FISHERIES ASSESSMENT

OF THE PROPOSED NAM CHOAN

HYDROELECTRIC POWER DEVELOPMENT

BY

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A practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of Master of Natural Resources Management.

EXECUTIVE SUMMARY

Hydroelectric and irrigation dams have been developed in Thailand for many years. These projects have caused significant changes in aquatic ecosystems due to increased water levels and the establishment of upstream reservoirs. The Nam Choan Generating Station will be the next hydroelectric plant on the River Kwae 150 km west of Bangkok. The project would result in environmental changes and affect fish living in the area right after the project commenced and probably continue for a long time after the project was completed.

The study was conducted by reviewing literature concerning environmental impacts e.g. climatology, water quality, etc. resulting from the former two hydroelectric dams which cause significant change on fish habitat and fish behaviour in the project area. Causes of species composition changes and the fish response to environmental changes as well as biology of fish existing in the project area were studied in order to improve fish habitat and manage environmental impacts resulting from river impoundment. In addition, fish sample from Srinakarin and Khao Laem reservoirs and from the proposed Nam Choan area were collected and tested to determine the amount of mercury concentration in fish muscle. The amount of mercury in fish from each location were compared to determine whether the mercury concentration could be accumulated in fish due to impoundment especially those living in tropical regions. The objectives of this research project are:

1. To examine the habitat requirements for each important fish species existing in the area which will be affected the Nam Choan project.
2. To predict possible impacts on fish of the Nam Choan project by reviewing the literature and other sources of information relating to former projects.
3. To determine the quantity of mercury in fish muscle following impoundment.
4. To use this information to suggest corrective works and reservoir management schemes for maintaining the original or new but acceptable conditions for the Nam Choan project.

Fish and fish habitat were affected from the impoundment. There are some species that were declined and some species were increased in their population because of habitat changed. Therefore, recommendations in fisheries management were provided. Moreover, mercury concentration in fish in reservoirs were found to be higher than at an unflooded reference site.

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CHAPTER 1

INTRODUCTION

Hydroelectric and irrigation dams are man made development projects which cause significant changes in aquatic ecosystems. The Aswan Dam in Egypt, for example, caused environmental impacts such as sedimentation, coastal erosion and seismic movement (White 1988).

However, the concept of sustainable development could be applied to hydroelectric and irrigation developments by studying more carefully the environmental changes due to increasing water levels and the establishment of reservoirs upstream. Environmental impact assessment and prediction should be carried out and protection plans should be provided as well as appropriate management plans for affected water resources.

"Man made modifications that bring rapid changes are not necessarily deleterious. A good knowledge of physical, biological and social conditions in which those restraint of negative impacts may render such projects acceptable and at times desirable. The experience gained in the evaluation of actual diversions will allow as to better use this type of management, when judged appropriate, in the development of natural resources of a country." (Roy and Messier 1989)

In Thailand, there are hydroelectric and irrigation developments in many parts of the country. The largest hydroelectric reservoir is the Ubolratana reservoir. This reservoir is located 500 km northeast of Bangkok. It has a surface area of 41,000 ha and an average depth of 16 m at maximum storage capacity (Pawaputanon 1987). Following impoundment, there were many adverse environmental changes including physical, chemical, biological characteristics and also changes in the fish species composition in the reservoir (Bhukaswan and Pholprasith 1976). Moreover, sedimentation is the most severe problem in the reservoir after impoundment. Calculated from resent deposit rates, it was predicted that the Ubolratana reservoir would be filled in the next 80 years (Benchakarn, pers. comm.).

The Mae Klong River Basin is an area that is comprised of several rivers with high potential of hydroelectric development e.g. Mae Klong, Kwae Yai, and Kwae Noi River. The water flow from Kwae Noi, Kwae Yai and their tributaries feed into the Mae Klong River (Wildlife Fund Thailand 1987). Because of their high rate of flow, Kwae Yai and Kwae Noi rivers have been used for hydroelectric development for nearly three decades. Three hydroelectric dams and an irrigation dam have been built on the Kwae Yai and Kwae Noi rivers i.e. Srinakarin, Tha Tung Na and Khao Laem hydroelectric dams and Vachilalongkorn irrigation dam (Wildlife Fund Thailand 1987). These river impoundments resulted in many environmental changes, particularly, impacts on fish species due to changes in the water regime. Many of these fish species will be reduced in numbers because of environmental changes unless they can adapt to the new environment.

Nam Choan Generating Station

The Nam Choan generating station will be the next hydroelectric generating station on the Nam Choan stream which is a tributary of Kwae Yai River. The power plant will be built upstream of the Srinakarin reservoir with the capacity of 580 megawatts (Kemf 1986). The reservoir, flooded area 142 km^2, would be created by Nam Choan Dam (A Wildlife Biologist, 1987). It is one of the alternatives to supply energy to the Electricity Generating Authority of Thailand (E.G.A.T.) since E.G.A.T. will require additional energy sources in the near future. The project will include the construction of a transmission line and access road which will require cleared right-of-way crossing preserved forest areas and streams.

1.1 PROBLEM STATEMENT

On the basis of experience with existing hydroelectric projects, it has been realized that the Nam Choan project could result in physical, chemical, and biological changes. There would be environmental impacts from all project activities. Fisheries could be affected by environmental changes due to river impoundment as well as stream crossing by access roads and transmission lines.

Problems could occur at the beginning of the project through the construction period e.g. increase fishing pressure from construction workers and degradation of water quality. The impacts could continue for a long time after the project was completed e.g. loss of fish habitat, loss of important fish species, and elevated mercury concentrations in fish muscle which has been documented in fish from reservoirs in temperate regions. The problem could exist in tropical region as well because there are many suitable conditions for elevated mercury levels in fish muscle in tropical zones similar to those in temperate regions. However, there has been no investigations concerning this problem in tropical regions.

To improve fish habitat and manage environment impacts from river impoundment or road construction, studies of the causes of species changes and the fish response to environmental changes are required. Fish species existing in the River Kwae upstream from Srinakarin Reservoir must be studied as to their habitat suitability. Information concerning impacts on fish behavior caused by former projects downstream such as Srinakarin and Khao Laem dams could be useful to predict environmental impacts. A description of improvements that should be implemented in the project to mitigate the predicted environmental impacts should be provided.

1.2 OBJECTIVES

The intent of this study is to examine potential environmental impacts which could occur as a result of the Nam Choan project. The environmental changes and undesired negative impacts from the project would never be predicted unless the relevant information such as details concerning how each fish species responds to environmental changes and information on fish habitat changes due to impoundment in already developed dam projects in Thailand have been studied. Therefore, each fish species should be studied for their habitat requirements and the new habitat resulting from former project impoundments should be reviewed. The objectives of this research project are:

1. To examine the habitat requirements for each important fish species existing in the Nam Choan project area.

2. To predict possible impacts on fish by reviewing the literature and other sources of information concerning fish behavior in already developed projects.

3. To determine the quantity of mercury in fish muscle following impoundment.

4. To recommend corrective works and reservoir management schemes for maintaining the original or new but acceptable conditions for the Nam Choan project.

CHAPTER 2

LITERATURE REVIEW

Introduction

The Nam Choan Hydroelectric Dam will be built in Karnchanaburi province to provide additional energy for future requirements. The construction site will be located in Thung Yai Naresaun and Huay Kha Khaeng wildlife sanctuary which were established to preserve the largest, least disturbed and richest natural areas in Thailand (Wildlife Fund Thailand 1987). The reservoir will result in the loss of 590,000 rais or 94,400 ha of forest area and will also cause fish and wildlife population changes (Wildlife Fund Thailand 1987). Aquatic habitat in the Nam Choan reservoir would be affected because of the new water flow regime. The reservoir will turn upstream river habitat into lake-type habitat. Fish living downstream will be affected by drawdown water flow and low water quality released from the reservoir (Environment Canada 1989). These new aquatic habitats could cause the fluctuations of fish species composition in the reservoir. Some species that perform well in the new habitat will increase their numbers while some species will be unable to adapt to the new aquatic systems. Moreover, fish standing biomass might increase in the initial period of impoundment because of the enrichment of the reservoir with nutrients derived from the decomposition of organic matter during flooding. This results in the explosive growth of phytoplankton (Pawaputanon 1987). Flooding over the vegetated area also provides young fish with shelters protecting them from predators. Therefore, both negative and positive potential impacts on fish from the Nam Choan project require further studies. The information obtained could be used to develop fishery and water management plans for the project. The fishery and water development plans could provide appropriate conditions for reservoir management such as controlling spawning grounds and spawning season and also controlling aquatic vegetation. These activities will create a habitat that is suitable for most of the species living in the project area.

2.1 Potential impacts on fish in the proposed Nam Choan project.

2.1.1. Increased fish populations

The impoundment will create a reservoir with a greatly increased water area. Normally, fish yield in new reservoirs increases in the first few years after impoundment (Bhukaswan and Pholprasith 1976, Pawaputanon 1987). Reservoirs show increases in nutrients derived from the decomposition of organic matter. This will cause explosive growth of phytoplankton. Young fish can use this food for their growth and will increase their survival rate. Vegetation such as green and bluegreen algae also grow rapidly along the shoreline and in shallow water of less than 6 m depth (Bhukaswan and Pholprasith 1976). This vegetated area provides shelter for young fish to protect themselves from predation of bigger fish (Pawaputanon 1987). Therefore, many fish species will increase in abundance in the new reservoir during the first few years after impoundment. However, the population will decline after the first few years because of reductions in water quality and nutrient supply.

2.1.2. Fluctuation in fish species composition resulting from habitat change

After a few years, fish species composition in the impoundment will be changed because of changes in the aquatic environment. Several species may disappear following the impoundment. Other species may become dominant because they perform well in the new habitat (Bhukaswan and Pholprasith 1976).

There are number of environmental impacts from the impoundment that change fish species composition in the reservoir including:

2.1.2.1 Water quality

As mentioned earlier the increasing water level in the reservoir will flood vegetation, organic litter and organic matter in the soil. The organic matter will decompose, resulting in increasing levels of nutrients and organic acids in the reservoir (Potter 1980). Algal blooms and macrophyte growth are expected to increase in the reservoir due to high nutrient levels. Algal populations will collapse and decompose, resulting in severe oxygen depletion (Environment Canada 1989). Low levels of dissolved oxygen might occur in the reservoir, especially at the bottom of deep reservoirs such as those behind hydroelectric dams, where light intensity is not enough for photosynthesis. As stated by Petts (1984), in the epilimnial layer, water-mixing by wind and wave action, combined with photosynthetic production by algae, dissolved oxygen levels will be increased to nearly saturation. Photosynthetic activity of algae depends on temperature and light intensity. Therefore, in the hypolimnion where it is cooler temperature and lower light intensity, photosynthetic activity will decline.

In summer, water temperatures will increase as a result of higher air temperature and also by the decreasing velocity of water flow. High temperatures will result in lower solubility of gases (particularly oxygen and carbon dioxide)(Gosz 1980 and Cole 1983). Metabolic rates of fish increase as temperature goes up, leading to a higher demand for oxygen in fish respiration (Piper et al 1982). Each fish species has its own optimal temperature range for growth and reproduction. Fish will be more susceptible to disease because of temperature changes (Piper et al 1982). Furthermore, in summer as temperatures increase and the fish increase their metabolic rate, dissolved oxygen levels may drop to lethal level for the fish.

Water level fluctuation in hydroelectric reservoirs is one of the problems causing fish population to change. After impoundments water levels in the reservoir will be lowered in summer because of evaporation. The amount of water evaporated from reservoirs depends on the surface area. Gaboury and Patalas (1984) studied the influence of water level drawdown on fish populations in Cross Lake, Manitoba and reported that when river flow decreases, conductivity and total dissolved solids also decreases. In contrast, nutrient and organic carbon concentrations increase. These changes resulted in low oxygen levels and a declining fish population. Water drawdown also increases the stress on fish living in reservoirs by increasing the concentrations of toxins such as pesticides which are used in agricultural activity. This stress could result in causing the fish to be susceptible to disease and infection from bacteria existing in the water. Although recently there has been no agricultural activities around the Nam Choan project, there will be an influx of people into the area because of the hydroelectric development as was the case during construction of other reservoirs throughout Thailand.

2.1.2.2 Fish habitat and spawning area

Water turbidity is a remarkable physical feature of Thai reservoirs and the major cause of water turbidity is soil erosion (Pawaputanon 1986). After impoundment, turbidity in reservoirs tends to increase, especially after a rainfall. Carp are commonly found to be the most numerous fish in Thai reservoirs except in the south (Pawaputanon 1986). Turbidity could increase carp egg mortality. Other species, such as *Anabas, Botia, Trichogaster* and *Clarias,* would also be affected by environmental changes causing declining in spawning success (Pawaputanon 1986).

The increasing of water level and changing from riverine habitat to reservoir habitat could result in the loss of fish spawning area (Environment Canada 1989). However, some fish species can survive in reservoir environments and increase their abundance after impoundment (Pawaputanon 1986).

The spawning season of fish in Thailand begins in the rainy season when the water level is rising with more fresh and cool runoff water arriving from upstream. Spawning may be more than once a year in some species (Bhukaswan and Pholprasith 1976). Therefore, water level management could be used to increase fish spawning downstream and also to control aquatic weeds in reservoir.

2.2. Mercury in fish

Mercury contamination in aquatic environments has been studied as a critical issue for many years. Many countries in Europe, North America and Asia, especially Japan, have studied the consequences of mercury absorption and toxicity as well as distribution of mercury in the biota since the outbreak of mercury poisoning in Minamata, Japan, caused by the consumption of contaminated fish (Hartung and Dinman 1972 and Park et al. 1980). Other outbreaks of methyl mercury poisoning took place in Iraq in 1971-1972 and in many other parts of the world (Canada-Manitoba Mercury Agreement 1987). Studies of the signs and symptoms of methyl mercury poisoning and sources of methyl mercury in the environment, therefore, have been carried out widely. The results of these studies should help scientists more fully understand the effects of mercury in the environment. Ecological systems could be improved and human health could be protected from mercury contamination.

Sources of mercury in the environment are not only from industrial activities or man's actions such as power production, mining, and smelting operations, but also from biological sources or as a natural result of land erosion and bacterial methylation. Mercury consumption patterns in the United States during 1970-1973 are shown in table 2-1. The major sources of anthropogenic mercury include emissions from mining (the smelting of ores to extract metals such as lead, zinc and copper), energy and manufacturing related activities (Williamson 1986 and National Research Council 1978).

Table 2-1 Mercury Consumption in the United States, 1970-1973. (10^6 g)

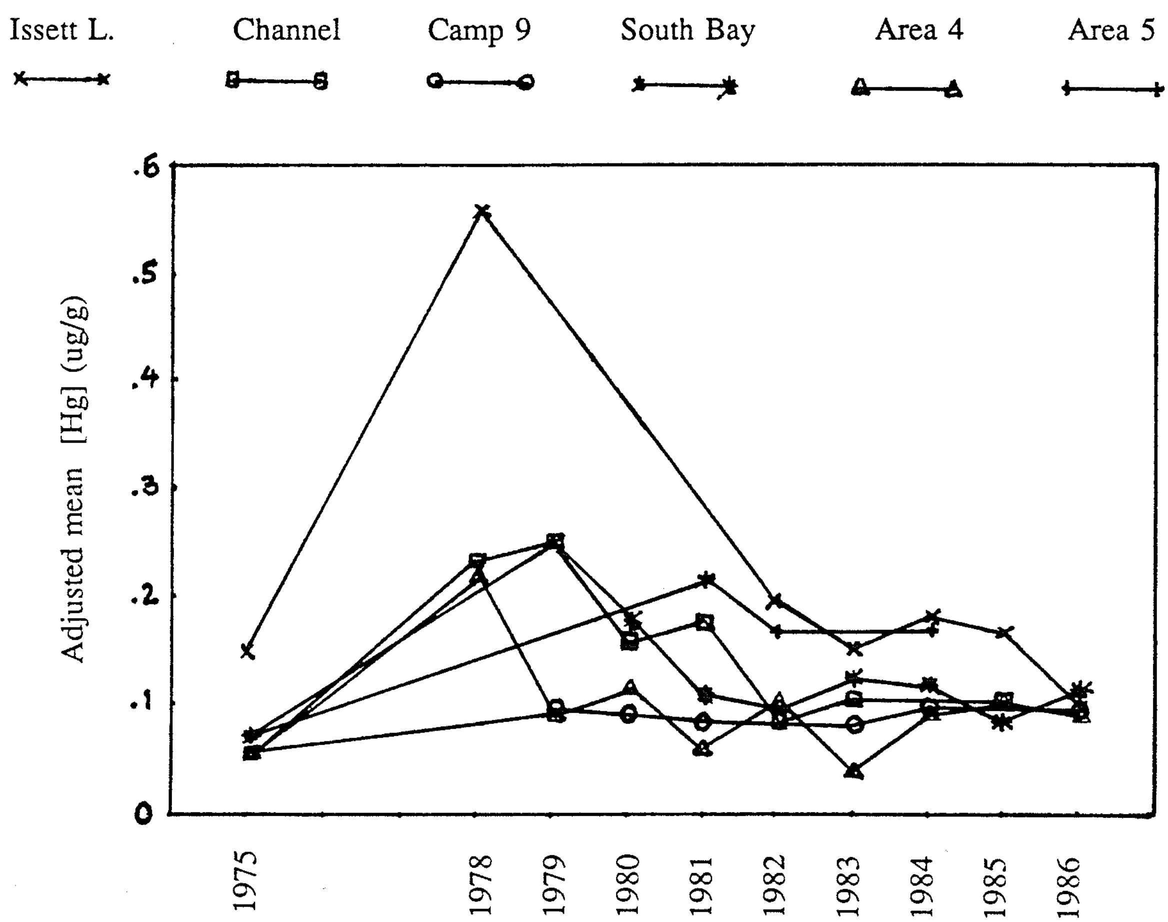
End Use Activity	1970	1971	1972	1973
Agriculture	62.3	50.8	63.2	62.9
Catalysts	77.0	34.3	27.5	23.2
Dental preparations	78.6	64.4	102.6	92.2
Electrical apparatus	548.7	572.6	535.0	619.2
Caustic chlorine	516.4	421.5	396.2	449.6
Laboratories	62.1	46.7	20.4	22.6
Industrial instruments	166.2	134.4	225.0	246.1
Paints	355.9	296.0	282.8	261.5
Pharmaceutical	23.7	23.0	19.9	20.8
Other	209.3	170.0	147.2	69.1
Total (rounded)	2100	1814	1820	1867

Source : The National Research Council [Derived from U.S. EPA (1975 b)]

In some areas such as newly flooded reservoirs, mercury concentrations in fish muscle are found at higher levels than in the original unflooded areas. Diversion of the Churchill River in Northern Manitoba, Canada, for example, created environmental changes in the Southern Indian Lake by raising the lake level of approximately 3 meters and increasing the lake area 21%

(Bodaly et al. 1984 and Canada-Manitoba Mercury Agreement 1987). One of the significant environmental impacts resulting from reservoir impoundment was the increasing of mercury levels in fish muscle which was not predicted before the project was implemented (Canada-Manitoba Mercury Agreement 1987). This was documented by Bodaly et al. (1988) based on data collected from 1975 to 1986, before and after the impoundment periods of Southern Indian Lake that mean concentrations of muscle mercury increased after impoundment (figure 2-1). This shows the impact of river impoundment that could increase mercury levels in fish to some extent and then the mercury levels start to decline.

Figure 2-1 Mean whitefish muscle mercury concentrations adjusted by analysis of covariance for six sampling sites, 1975-1986.



Jernelov reported in Hartung and Dinman (1972) that, in Sweden, there are three compounds of mercury released into the aquatic environment. The compounds are elementary mercury, phenylmercury and bivalent inorganic mercury. These three compounds tend to move into the sediments first. Phenylmercury mainly enters the sediments along with elementary mercury which is not very soluble in water. The bivalent mercury is methylated to monomethyl or dimethylmercury. Monomethylmercury will be taken up by fish, algae and other living aquatic organisms while dimethylmercury will move to the atmosphere.

Conditions for Methylation

The production of methyl mercury depends on physical and chemical conditions in the system which are reported by Jernelov (1972) and Canada-Manitoba Mercury Agreement (1987) as followed:

(a). Methylation of mercuric sulphide

Mercuric sulphide is the special form of bivalent mercury which has to be oxidized before methylation can take place. It almost insoluble in water. Mercuric sulphide may be added into the process of methylation of elementary mercury which results in the formation of a smaller amount of methyl mercury than if inorganic bivalent mercury is added.

(b). Anaerobic and aerobic conditions

Methylation of mercury can occur in both anaerobic and aerobic conditions. From laboratory experiments, the methylation activity is higher under anaerobic conditions than under aerobic conditions, provided the sulphide concentration remains low. Other studies show that biological mercury methylation is strongly influenced by oxygen concentration, increasing dramatically when oxygen levels decline below 3-4 ppm (Canada-Manitoba Mercury Agreement 1987). However, in lakes or rivers, hydrogen sulphide will be formed at the bottom when oxygen disappears. Therefore, mercuric sulphide will be formed causing a lower rate of methylation. Thus, in freshwater, higher methylation rates will be expected under aerobic conditions than under anaerobic conditions.

(c). Effect of pH on methylation

Jernelov (1972) reported that the amount of mercury in fish will be higher at lower pH because total methylation is dependent upon pH. At high pH, more of the methylating mercury will be converted to dimethylmercury and released into the air. In contrast, at low pH, monomethylmercury is produced rather than dimethylmercury resulting in higher methylation and, finally, methyl mercury will accumulate in fish. However, Canada-Manitoba Mercury Agreement (1987) reported that pH values of approximately 6.0-7.5 are optimum for the net production of methyl mercury.

(d).Temperature

Although it is reported in Canada-Manitoba Mercury Agreement (1987) that mercury methylation rates are highest in mid-summer, according to subsequent experiments, there is no evidence that shows any obvious relationship between temperature and mercury concentration in fish.

Methylation Processes

As stated in the Canada-Manitoba Mercury Agreement (1987), methyl mercury is produced and destroyed by a variety of microbes. There are a number of experiments confirming organic materials tend to stimulate the bioaccumulation of mercury in fish. Organic material such as black spruce boughs and moss-peat material has been shown to increase mercury levels in fish (Canada-Manitoba Mercury Agreement (1987). Moreover, Hamilton (1972), Armstrong and Hamilton (1973) in Rudd et al. (1979) reported that mercury contaminated Clay Lake sediments (located in Wabigoon-Clay Lake-English River System, Ontario) which received a discharge of 10,000 kg mercury during 1962-1969, were not a major source of mercury to crayfish, but that mercury accumulation from contaminated water or from food sources was a major routes for mercury bioaccumulation. It was also concluded by Canada-Manitoba Mercury Agreement (1987) that the mercury levels in soil, sediment, and vegetation of the agreement area (Southern Indian Lake) are normal as compared with levels in other non-polluted regions. There was no evidence of temporal or spatial trends in mercury levels, of any depletion in mercury levels following flooding, or of any relationship between mercury levels in fish and in sediments.

Elevated methyl mercury levels found in fish must have resulted from processes which increase the rate of conversion of other forms of mercury to methyl mercury. The processes occur naturally, caused by a variety of microbes (Canada-Manitoba Mercury Agreement 1987). A number of physical, chemical, and biological parameters that vary between aquatic ecosystems could change the net production of methyl mercury. Bioaccumulation occurs when the balance of methylating and demethylating processes are changed or the rate of uptake exceeds that of elimination (National Research Council 1978).

Colwell et al. (1975) reported that mercury accumulation in some aquatic organisms is significantly higher in water containing mercury-metabolizing bacteria than in the organisms held under controlled conditions without mercury-metabolizing bacteria. Therefore, bacteria should play an important role in the uptake of mercury by organism in aquatic systems. The production of methyl mercury depends on the amount of mercury added and the efficiency of methylators which are the types of bacteria in the ecosystem.

Newly constructed reservoirs with significant flooding of soils and vegetation will cause increased mercury levels in fish muscle (Bodaly et al 1984). Increased bacterial production due to the degradation of flooded terrestrial vegetation, peat and humus will probably result in an increased rate of mercury methylation (Beizer and Jernelov (1979); Bisogni (1979); Furutani and Rudd (1980) in Bodaly et al 1984). Methyl mercury is transferred through the food chain or enters fish through the gills. Mercury may be absorbed by phytoplankton (Ramlal et al. 1987). Tam and Armstrong (1972) reported that contamination by mercury varied with the position of the fish in the food-chain and with geographical location. Mercury levels are highest in predatory fish such as in pike and walleye. The relationship between length (or weight) and mercury content in various groups of fishes might be used to predict a certain critical size for selective fishing. Scott (1972) investigated mercury contamination in commercial fish and concluded that:

1. There is a fairly close relationship between fish size and mercury content within groups.

2. Relationship parameters are highly diverse. Some species could lose their mercury content as growth proceeds and some could absorb and retain mercury at a rate equivalent to more than the cube of length increase.

Mercury Toxicology

Signs and symptoms of methyl mercury poisoning would appear in the most sensitive individual adults at blood concentrations between 200 and 500 parts per billion (ppb) (Canada-Manitoba Mercury Agreement 1987). The signs and symptoms of methyl mercury poisoning in humans include disturbance of superficial and deep sensation, constriction of the visual field, lack of coordination, and impairment of speech, hearing and gait. The important features of methyl mercury poisoning is damage to the nervous system, especially the central nervous system.

There is still no specific medical treatment for the effects of methyl mercury poisoning. Therefore, mercury testing programs are needed for early detection and prevention of poisoning. In addition, mercury levels in fish have also been limited to the acceptable level as defined by Canadian and United States guidelines. The allowable level for total mercury in fish sold in Canada is 0.5 parts per million (ppm). In the United States, the allowable mercury level in fish was raised to 1.0 ppm total mercury in 1979. In 1984, the limit in the United States was changed from 1.0 ppm total mercury to 1.0 ppm methyl mercury (Canada-Manitoba Mercury Agreement 1987).

In Northern Manitoba reservoirs, the rates of mercury methylations appeared to increase with increasing water temperature although there was often a "lag" period (Bodaly 1991, pers. comm.). There are reports showing that high mercury levels in newly impounded reservoirs are quite widespread in North America, including warmer areas such as in Arizona, South Carolina, Utah, Idaho, and Mississippi (Bodaly et al 1984). Therefore, the possibility of increased rates of accumulation of methyl mercury exists for Thai reservoirs even though water temperature is quite high compared to water temperatures in North America.

2.3 Conclusion

Environmental changes after impoundment are the certain results in the already developed hydroelectric reservoirs. Water quality and fish species composition are changed because of changes in the environment. These results could be expected as significant effects in the proposed Nam Choan hydroelectric project.

Reservoir management could help improve environmental condition so that fish can survive and actually increase their populations. For example, water improvement could be done by increasing oxygen and controlling toxic waste discharged into the water. These activities could improve fish habitat and create better conditions for fish survival and reproduction.

The introduction of new fish species into reservoirs for the purpose of (i), increasing productivity by utilizing excess food not used by local species and, (ii) of controlling aquatic vegetation which is one of the reservoir management plans appropriate for fisheries development and would also serve the goal of sustainable development. Chinese silver carp and bighead carp could be stocked because they are plankton feeders. Grass carp, Thai silver carp and the snake-skinned gouramy could be introduced to control aquatic vegetation. *Pangasius sutchi* and *Probarbus jullieni* feed on benthic organisms and mollusc (Bhukaswan and Pholprasith 1976).

More studies are required to learn how introduced fish adapt to life in these new conditions and, also, to determine if they will interfere with native species. Introduced species should be able to live in the new environment, compatible with native species and be able to reproduce in the new water body. These factors should be considered together with their growth rate in the reservoir (Bhukaswan and Pholprasith 1976). Other mitigation plans should also be considered; for example, their suitability and any adverse effects they might have on the various fish species in the same reservoir. Consequently, it should be kept in mind that any mitigation plan should be made after carefully study of the conditions in the reservoir and in the aquatic systems both upstream and downstream of the impoundment.

CHAPTER 3

METHODOLOGY

This study focuses on the environmental impacts on fisheries of the Nam Choan project. The scope of the studies included fish habitat requirement such as spawning areas and water quality that would be affected by the impoundment. The study of the ability of fish to adapt to the new habitat was also done by reviewing data concerning habitat suitability before and after the impoundment in such existing projects as the Srinakarin and the Khao Laem dams. In addition, mercury concentrations in fish muscle, which has been a major problem in North America, was examined from fish in the proposed project area and also in the existing hydroelectric reservoirs nearby.

The study was divided into three parts. The first part was a study of the habitat requirement of the major fish species existing in the Nam Choan area and their ability to adapt to reproduce in the new habitat. Environmental impacts from similar previous projects were reviewed from literature. Fish spawning behavior (upstream migration) as well as physical requirements such as water quality and water flow regimes suitable for each fish species were studied. Moreover, a study of changes in fish behavior caused by environmental changes was done as well.

The second part of the study was the examination fish habitats to identify the significant ecosystem changes resulting from impoundment. The literature reviews were accomplished by surveying the articles concerning fishery impacts in the area including Srinakarin, Khao Laem and the proposed Nam Choan project area. Information was obtained from the following agencies:

1. Electricity Generating Authority of Thailand (E.G.A.T.)
2. National Inland Fisheries Institute (N.I.F.I.)
3. National Environment Board, Thailand.
4. National Economic and Social Development Board, Thailand.

etc.

Information collected was analyzed by dividing fish species into three groups i.e. those whose

a.) Behavior will not be affected by environmental changes.

b.) Behavior will be changed, but the environment can be improved.

c.) Behavior will be changed, but the environment cannot be improved.

The third part of the study was to determine the effect of reservoir formation on mercury concentrations in fish muscle. Fish samples were collected from commercial catches from the Srinakarin and Khao Laem reservoirs and also from the Nam Choan area. Samples of fish of the same species from all three locations were compared to determine if there were differences in mercury concentrations among sites. Fork length and round weight were determined for all fish sampled. Samples of axial muscle were frozen with dry ice to sent back to the Freshwater Institute in Manitoba to test mercury levels. More details will be presented in chapter 6.

CHAPTER 4

CONSEQUENCES OF THE IMPOUNDMENT IN THE KWAE YAI AND KWAE NOI RIVER

4.1 Background of the Kwae yai and Kwae Noi Development Project

The Kwae Yai and Kwae Noi rivers are the main tributaries of the Mae Klong River. Their origins are in the mountainous region of the Thai-Burma border and the rivers flow down to the town of Karnchanaburi where they join forming the Mae Klong river. The Kwae Yai river, 451 kilometers in length (Sidthimunka 1972), rises in the mountainous area in Tak province. It joins several main tributaries such as the Nam Mae Chan and Huai Kha Khaeng stream before it unites with the Kwae Noi river at Karnchanaburi. The slope of the Kwae Yai River bed in the upper reach is quite steep, ranging from 1:40 at its uppermost portion to 1:700 near its confluence with the Huai Kha Khaeng (Sidthimunka 1972). Downstream from the Huai Kha Khaeng stream, the bed slope is 1:2000 and about 1:3000 at the lower end of the river. Generally the river bed is sloping with fine sand mixed with sediments on the surface (Sidthimunka 1972). In the upstream reach of the proposed Nam Choan damsite the river bed is rock and fine sand (Team Consulting Engineers CO., LTD. 1980 and Chansawang et al 1986). Because of the high runoff, ave. 4,600 MCM per annum in the Kwae Yai river (Sidthimunka 1972), and the favourable topographic conditions, the river have been considered as an important water resource, offering the potential of huge hydroelectric development projects such as the Srinakarin, Khao Laem and Tha Thung Na dams. The development programs have been implemented since 1973 (Leenanond 1981). The Srinakarin and Tha Thung Na projects were put into operation in 1980 and 1982 respectively (Pal Consultant Co., Ltd. and Aggie Consult Co.,Ltd.1990). The last project is the Khao Laem dam which was impounded in 1984 (Chukajorn et al 1986).

4.2 Post Environmental Evaluation

The environmental impacts in the proposed Nam Choan project may be predicted by studying the earlier impoundments. Thus, post evaluation of the environmental impact from the Srinakarin and Khao Laem project will be useful for accurate prediction. In addition, physical information for each reservoir is necessary in terms of background information indicating feasible causes of environmental changes. General characteristics of each reservoir should, therefore, be studied.

4.2.1 The Khao Laem Reservoir

The Khao Laem reservoir was formed by a concrete-faced rockfill dam. The total storage is 8,860 MCM and a water surface is 388 km^2 at the normal high water level of 155.0 MSL. The reservoir has a live storage of 4,900 MCM (Pal Consultants Co.,Ltd. and Aggie Consult Co.,Ltd. 1990). The reservoir is located in Thong Pha Phum district of Karnchanaburi province on the Kwae Noi river which has its origin in Sangklaburi, Karnchanaburi province (Figure 4-1). There are three 100 MW generators in power station which can generate 777 million KWh annually. The reservoir has annual inflow of 5,500 MCM and the available drawdown is 20 m (Pal Consultants Co.,Ltd. and Aggie Consult Co.,Ltd 1990).

4.2.2 The Srinakarin Reservoir

The Srinakarin project located in the lower reach of the Kwae Yai river as well as the Tha Thung Na dam which is located 28 km downstream from the Srinakarin reservoir. The Tha Thung Na dam holds water discharged from the Srinakarin reservoir to improve water conditions before release into the Kwae Yai river. Moreover, water can be pumped back into the Srinakarin reservoir during the offpeak period when power produced exceeds the amount required. The Srinakarin reservoir has a total storage capacity of 17,745 MCM with the average annual inflow of 4,600 MCM. The highest generating capacity is 720 MW. The Tha Thung Na reservoir has a total storage capacity of 54.8 MCM and generating capacity is 38 MW (Pal Consultants Co.,Ltd. and Aggie Consult Co.,Ltd. 1990).

4.2.3 The Proposed Nam Choan Project

The proposed Nam Choan project include the Nam Choan and Thi Khong hydroelectric power stations. These two power stations will be the next development stage in the Upper Kwae Yai Project following the Srinakarin and Tha Thung Na projects. The two development schemes are located approximately 135 km upstream of the Srinakarin reservoir.

The Nam Choan scheme consists of a rockfill type dam which creates reservoir at a storage capacity of 5,950 MCM with a 185 m height. The available drawdown is 39 m and the generating capacity is 580 MW (E.G.A.T. 1981). The Thi Khong scheme, a concrete gravity dam, located 8 km downstream of the Nam Choan dam. The scheme will utilize the head remaining between the Nam Choan and Srinakarin reservoirs in which the potential power is 51 MW (E.G.A.T. 1981).

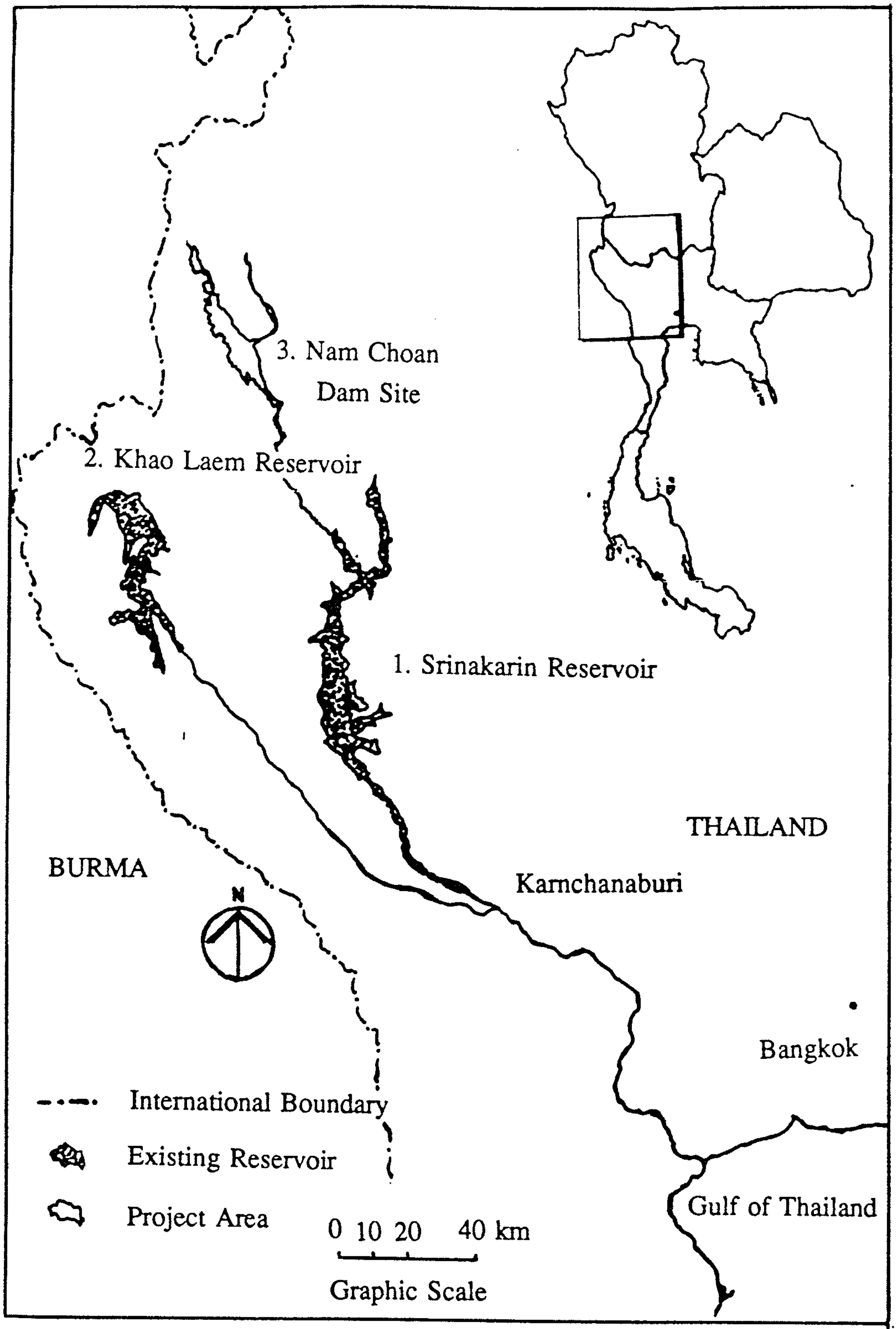


FIGURE 4-1 **MAP OF THE STUDY AREA IN THE MAE KLONG RIVER BASIN**

Table 4-1 The physical characteristics of the Khao Laem, Srinakarin, and Nam Choan dams.

	Khao Laem	Srinakarin	Nam Choan
Average Annual Inflow (MCM)	5,500	4,600	2,975
Maximum High Water Level (m,MSL)	160.5	185	373.8
Normal High Water Level (m,MSL)	155.0	180	370.0
Normal Minimum Water Level (m,MSL)	135.0	159	331.0
Available Drawdown (m)	20.0	-	39.0
Average Reservoir Drawdown (m)	-	-	8.0
Total Storage Capacity (MCM)	8,860	17,745	5,950
Reservoir Area (km^2)	388	419	137

(E.G.A.T. 1981, Water Impact Investigation Committee 1988, and Pal Consultants Co.,Ltd. and Aggie Consult Co.,Ltd. 1990)

The development of the Nam Choan hydroelectric dam was cancelled in 1988 because of wide spread protests from both public and private organizations. Experience from the Srinakarin and Khao Laem dams concerning the adverse impacts from impoundment attracted public interest in protecting the environment for future generations. Consequently, the project was considered not worthwhile at this time, however, the project could become an environmentally sound development project in the future in comparison with other alternatives such as a thermal plant using coal or natural oil and gas. These could create different kinds of pollution or hazardous waste problems. Nuclear power plant is one of the worst alternatives which not only create hazardous waste but also have high risk from nuclear accident.

Hydroelectric power development, therefore, could become a feasible alternative if the projects are carefully planned and provide all the appropriate specific mitigation procedures for each project.

The purpose of this report is to study the impacts of the former hydroelectric projects on fisheries and to recommend appropriate mitigation plans for the proposed Nam Choan hydroelectric project. Thus, Post Environmental Evaluation (PEE) of the Srinakarin and Khao Laem projects should be conducted to provide information for mitigating any adverse effects if the Nam Choan project is implemented.

4.3 Consequences of the Impoundment

4.3.1 Upstream The effects of the Srinakarin, Tha Thung Na and Khao Laem projects due to impoundment were studied by Pal Consultants Co.,Ltd and Aggie Consult Co.,Ltd. (1990). and they reported the following environmental impacts at the regional and provincial levels.

4.3.1.1 Climatology

Effects of the impoundment of the Srinakarin and Khao Laem reservoir were found to be minor at the regional and provincial levels. At the local level, post-dam air temperatures were lower than pre-dam temperatures in the hot season, but were higher during the cold season (Figure (4-2)-(4-9)). The annual average temperature dropped by about 2°C Monthly humidity in the post-dam period was higher. Rainfall data show a continued decreasing trend in the post-dam period.

4.3.1.2 Surface Water Quality

The Khao Laem reservoir receives wastewater discharged from mines located on upstream tributaries. The reservoir, therefore, has been contaminated by such heavy metals as Zinc, Copper, Lead and Chromium (Table 4-2)

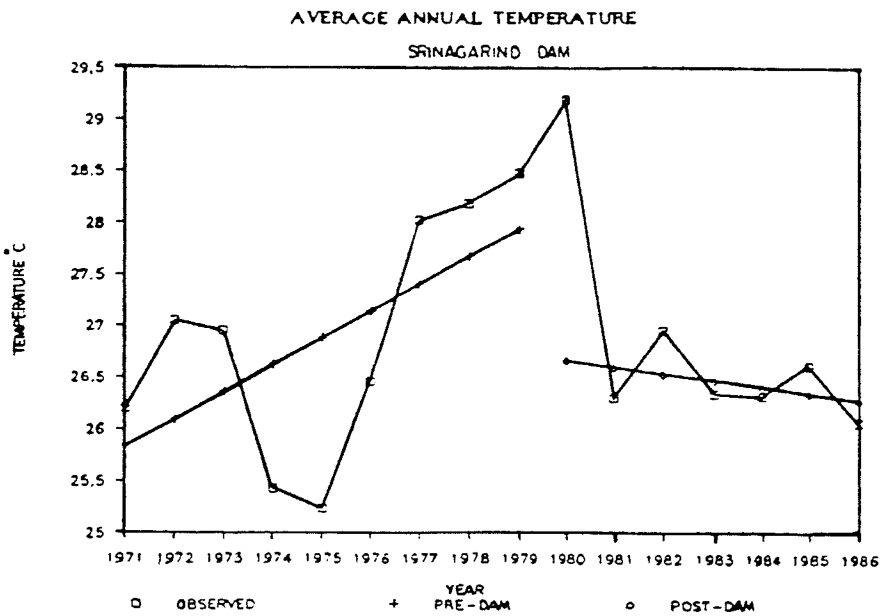


FIGURE 4-2

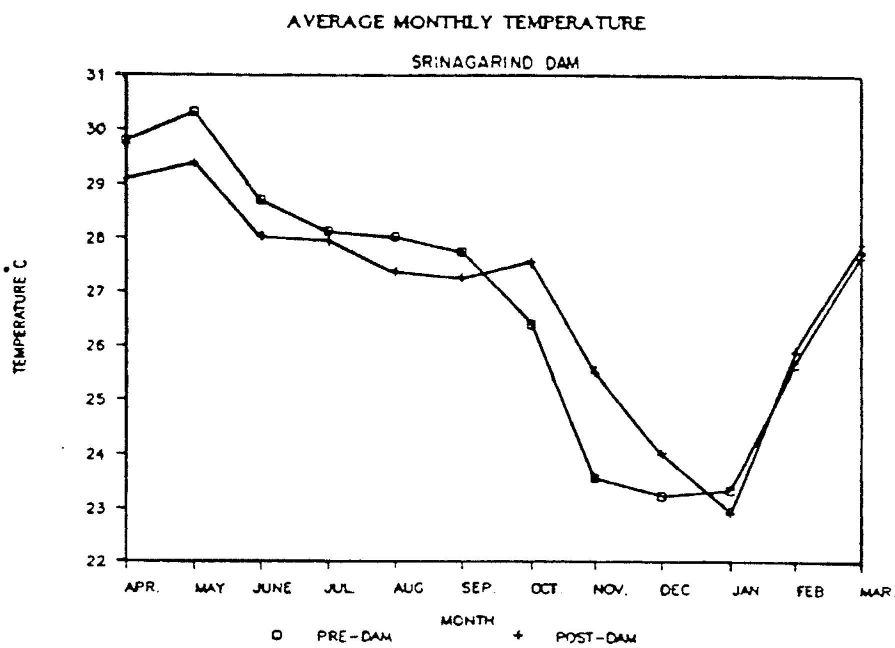


FIGURE 4-3

FIGURE 4-2, 4-3 AVERAGE TEMPERATURE OBSERVED BEFORE AND AFTER THE IMPOUNDMENT OF SRINAKARIN RESERVOIR. FIGURE 4-2 SHOWS TREND OF TEMPERATURE THAT DROPPED AFTER IMPOUNDMENT.

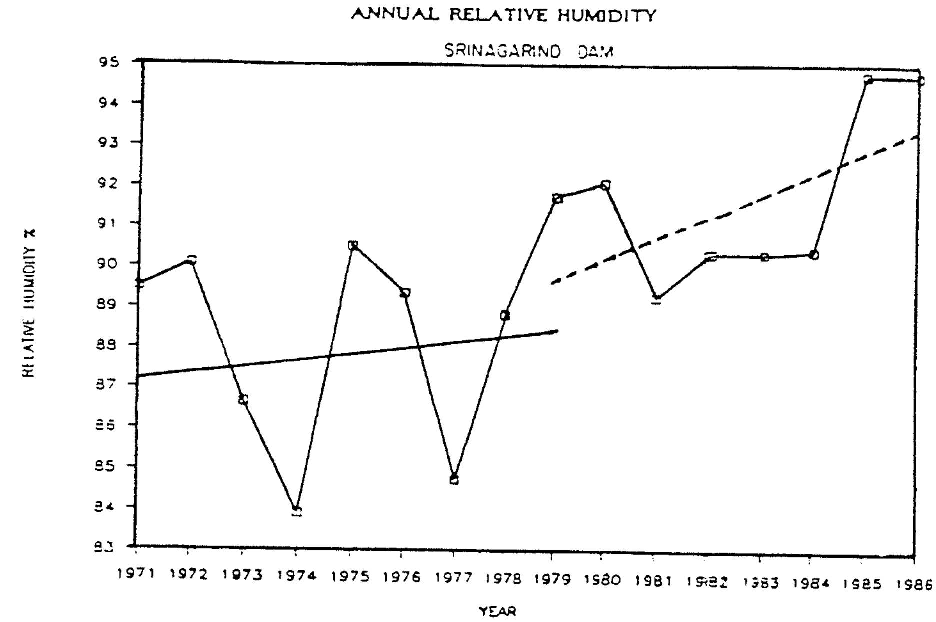


FIGURE 4-4

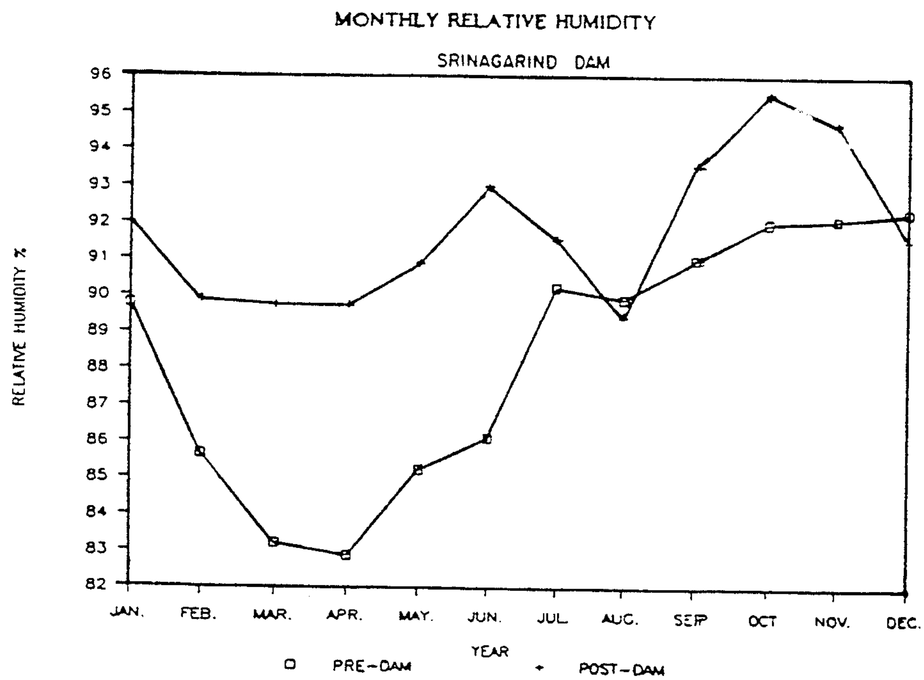


FIGURE 4-5

FIGURE 4-4, 4-5 RELETIVE HUMIDITY IN SRINAKARIN RESERVOIR THAT INCREASED AFTER IMPOUNDMENT.

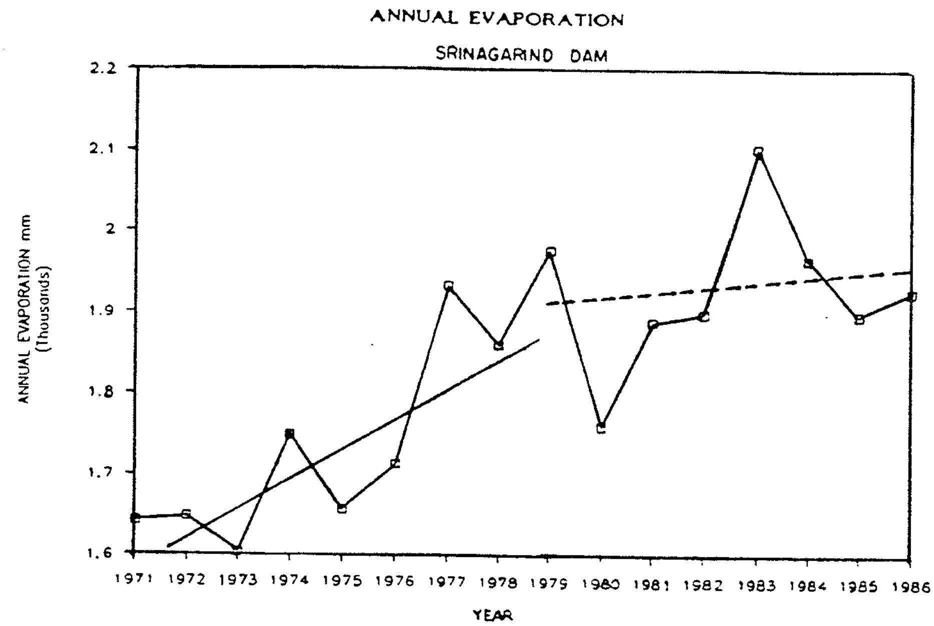


FIGURE 4-6

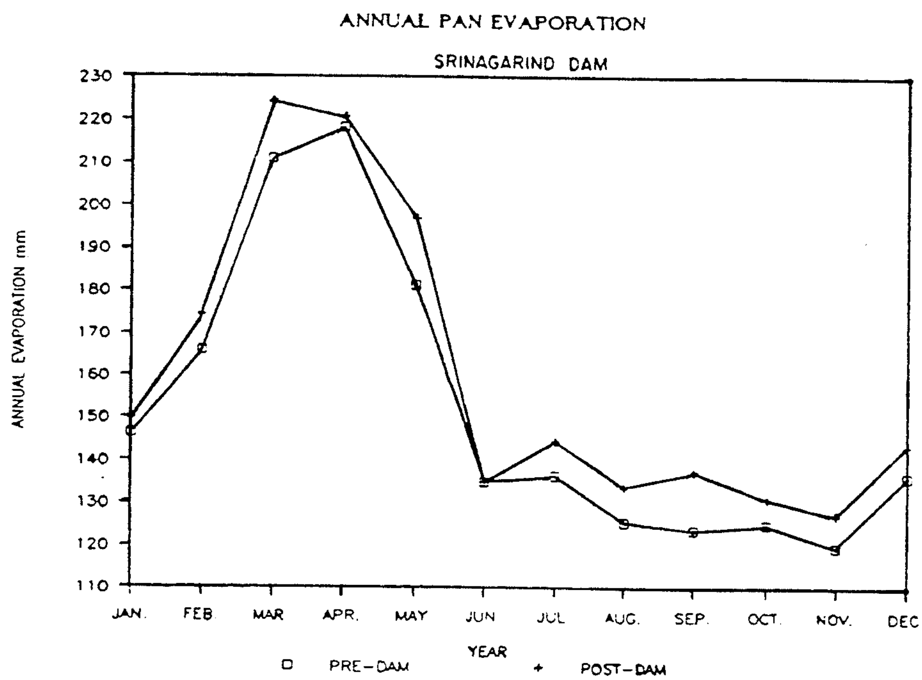


FIGURE 4-7

FIGURE 4-6, 4-7 EVAPORATION RATES BEFORE AND AFTER IMPOUNDMENT OF THE SRINAKARIN RESERVOIR.

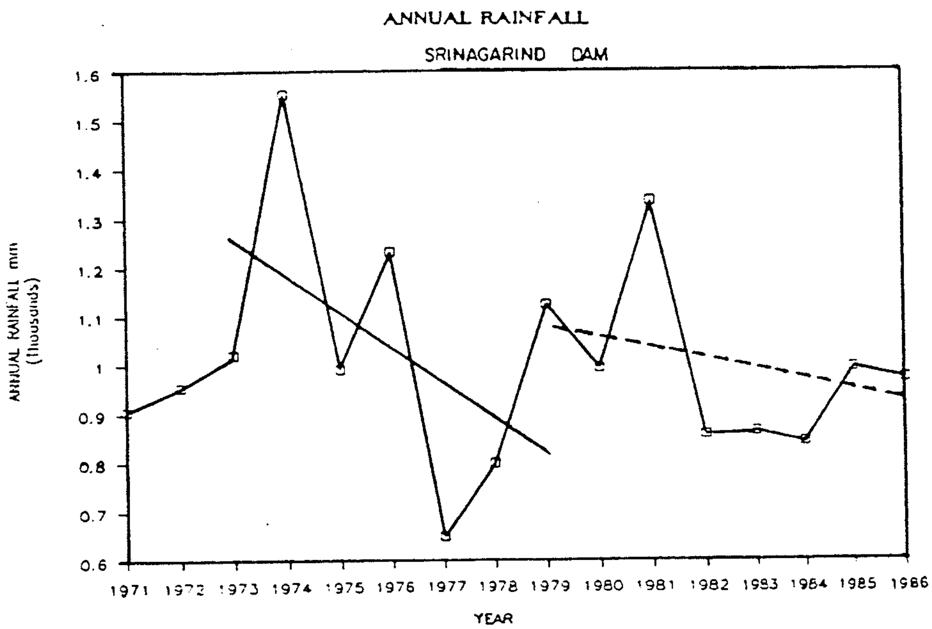


FIGURE 4-8

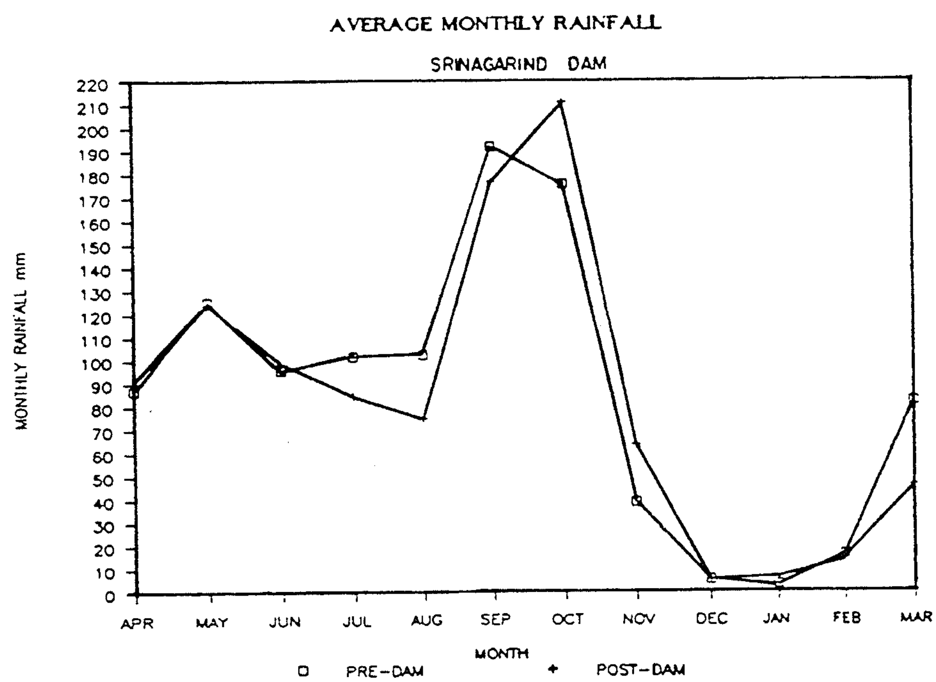


FIGURE 4-9

FIGURE 4-8, 4-9 RAINFALL CONDITION BEFORE AND AFTER IMPOUNDMENT OF THE SRINAKARIN RESERVOIR.

Table 4-2 Summary of water quality in upstream tributaries (April - July 1989) (Pal Consultants Co.,Ltd. and Aggie Consult Co.,Ltd. 1990).

Water Quality Parameter	Unit	Range of Value/Station			
		5.1	9	10	11
pH	Units	6.7-7.4	7.0-7.9	7.5-7.9	7.3-8.0
Transparency	m	2.4-3.3	2.0	1.9	2.1
Turbidity	Units	3.0-4.0	4.0-12	2.5-12	2.5-18.5
Alkalinity	mg/l	49-56	129-182	60	38-193
DO	mg/l	5.5-6.5	1.1-8.4	6.8-7.1	6.2-8.2
SS	mg/l	1.8-10.0	9.0-25	24-60	58-1108
Hardness	mg/l	51-58	150-184	58-208	17-86
Fe	mg/l	.04-0.1	0.24-0.59	.12-.99	.16-20.4
Mn	mg/l	.01-<.04	0.03	<.04-.11	.11-.74
Cu	mg/l	-	<10	-	<10
Zn	ug/l	-	50-60	-	40-180
Pb	ug/l	-	<10-10	-	<10-110
Hg	ug/l	-	<1-2	-	<1-1
Cd	ug/l	-	<2	-	<2
Cr^{+6}	ug/l	-	<20	-	<20

Notes 5.1 = Huai Malai ; 9 = Huai Ban Rai

10 = Huai Khayeng ; 11 = Huai Prachum Mai

Strong thermal stratification occurs in the Khao Laem reservoir in most periods of the year except in December-January when overturns occur. The situation is the same as in the Srinakarin reservoir because the reservoirs are relatively deep. Details of the thermal stratification will be reviewed later.

4.3.1.3 Erosion/ Sedimentation/ Watershed Management

The shoreline in the Khao Laem reservoir is usually stable and well protected by emergent weeds. Erosion of the reservoir bank is not serious except at a few locations near the outlet of Huai Pilok stream. This is caused by a lose layers of laterite, gravel, and sandy soil. Land slides also occur at an upper section of Huai Malai stream. Erosion in the Khao Laem catchment has resulted from many causes including on-site soil erosion caused by deforestation and agricultural activities, stream bank erosion, development of the road network. The total sediment load from soil erosion is 79,370 tons/annum representing 0.02 mm of the sediment of reservoir per year. In the catchment of the Srinakarin dam, total sediment load from soil erosion is 0.088 mm per year (Table 4-3).

Mining operations are the main source of the sediment load in the Khao Laem reservoir. The total load from the Pilok mining area is 895,000 tons per year. Including the sediment load from other areas which is 20% of the Pilok area, total sediment load from mining activities is 974,000 tons per year, but, the total sediment load from all activities estimated by E.G.A.T is about 1.25 million tons per year. At this sediment loading, the useful life of the reservoir would be 3,250 years.

TABLE 4-3

ESTIMATED ONSITE OR GROSS EROSION OF EACH SUBCATCHMENT AREA

BASED ON OBSERVED SOIL LOSSES FROM EXPERIMENTAL PLOTS

No.of Sub Catchment.	Drainage Area (ha.)	On-site Erosion from Various Land uses (tonnes/yr)			
		Forest Area	Agriculture Shipping Area	Mining Area	Total
1	1,200	14.71	613.80	-	658.51
2	2,450	105.49	1,093.68	-	1,199.17
3	1,225	101.43	-	-	101.43
4	2,725	146.66	886.99	-	1,033.65
5	22,650	1,669.12	2,317.10	-	3,986.22
6	4,625	325.51	645.19	-	970.70
7	26,300	2,025.21	1,712.13	-	3,737.34
8	65,375	5,142.40	3,039.94	-	8,182.34
9	2,050	132.40	419.43	-	551.83
10	13,125	1,086.75	-	-	1,086.75
11	5,475	453.33	-	-	453.33
12	37,075	3,069.81	-	-	3,069.81
13	4,275	307.95	516.85	-	824.80
14	4,225	349.83	-	-	349.83
15	4,300	356.04	-	-	356.04
16	16,200	1,274.29	753.30	-	2,027.59
17	8,175	521.21	1,216.44	120.52	1,858.17
18	2,625	123.89	1,049.74	-	1,173.63
19	3,300	150.28	1,381.05	-	1,531.33
20	20,875	1,175.35	3,882.75	527.55	5,585.65
21	11,025	593.37	3,588.64	-	4,182.01
Interbasin	75,711	6,268.87	-	-	6,268.87
Total		25,423.90	23,117.03	648.07	49,189.00

4.3.1.4 Aquatic Biology/ Fisheries/ Aquaculture

The amount of plankton in the Khao Laem reservoir has increased to a maximum of 66 million cells/m^3 causing algal blooms at certain times of the year. Benthic populations in the reservoir are not abundant particularly near the bottom layer where DO levels are low.

Floating weeds are not commonly found in the open areas of the reservoir while submerged weeds such as Ceratophyllum demersum and Utricularia sp. grow densely in several areas. Floating weeds, especially water hyacinth (Eichornia crassipes), grow well in the expanded section of the Huai Malai stream which forms part of the reservoir.

The impoundment of the Khao Laem reservoir has caused a significant reduction in carp and catfish populations, but increases in murrels and carnivorous fishes. Features of the fish populations in the Khao Laem reservoir are summarized in table 4-4.

Fish standing crop after impoundment is relatively high. In the pre-impoundment period, fish standing crop was 10.4 kg/rai (65 kg/ha). The standing crop has increased to ave. 16.4 kg/rai (102.5 kg/ha) after impoundment. There is no sign of decreasing fish standing crop in the past few year; hence trophic decline has not yet occurred in this reservoir.

Table 4-4 Summary of fish population in the Khao Laem reservoir

Items	12-13 Jan. 1989	21-22 Apr. 1989	28-30 Jul. 1989
1. No. of species	26	21	24
2. Standing crop, kg/ha			
- Range	30-243.12	31.25-94.37	29.37-215
- Average	107.5	63.12	136.25
3. Major groups, % by wt			
- Carp	-	7.2	9.3
- Catfish	-	4.2	5.7
- Carnivores	-	26.8	12.8
- Miscellaneous	-	55.6	12.6
4. F/C Ratio	-	2.7	0.37
5. Dominant species, by weight	*P. fasciatus* *N. notopterus* *C. striata* *X. cancila* *M. armatus*	*A. siamensis* *M. armatus* *N. notopterus* *P. fasciatus*	*P. fasciatus* *M. armatus* *A. siamensis* *N. notopterus* *C. micropeltes*

Notes : *P. = Pristolepis; M. = Mastacembelus; N. = Notopterus*

A. = Ambassis; C. = Channa X. = Xenentodon

(Pal Consultants Co.,Ltd. and Aggie Consult Co.,Ltd. 1990)

4.3.2 Downstream Water discharged from the reservoir upstream could result environmental impacts downstream including:

4.3.2.1 Surface Water Hydrology

The peak discharges of the rivers downstream, e.g. the Kwae Noi, Kwae Yai, and Mae Klong rivers, have been significantly reduced, especially in stream reaches just downstream of the dams. However stream flows have increased during the dry season to about twice the natural flow because of water management programs. These also control natural runoff during the rainy season by reducing water release to 20% of the natural runoff. Figures (4-10)-(4-13)) show average monthly runoff and monthly runoff in the Kwae Noi river, comparing pre-dam and post-dam periods.

4.3.2.2 Surface Water Quality

In the immediate downstream section of the reservoir, water quality is appreciably impacted by reservoir releases. DO levels are lower while CO_2 and BOD levels are higher than normal. At four km downstream of the Khao Laem power plant discharge, DO contents of around 4.0 mg/l are quite common, with an odor caused by H_2S being detected at some time. These downstream water qualities are the effects of anaerobic conditions in the reservoir bottom layers and also the effects of wastewater from tourism related activities along the river.

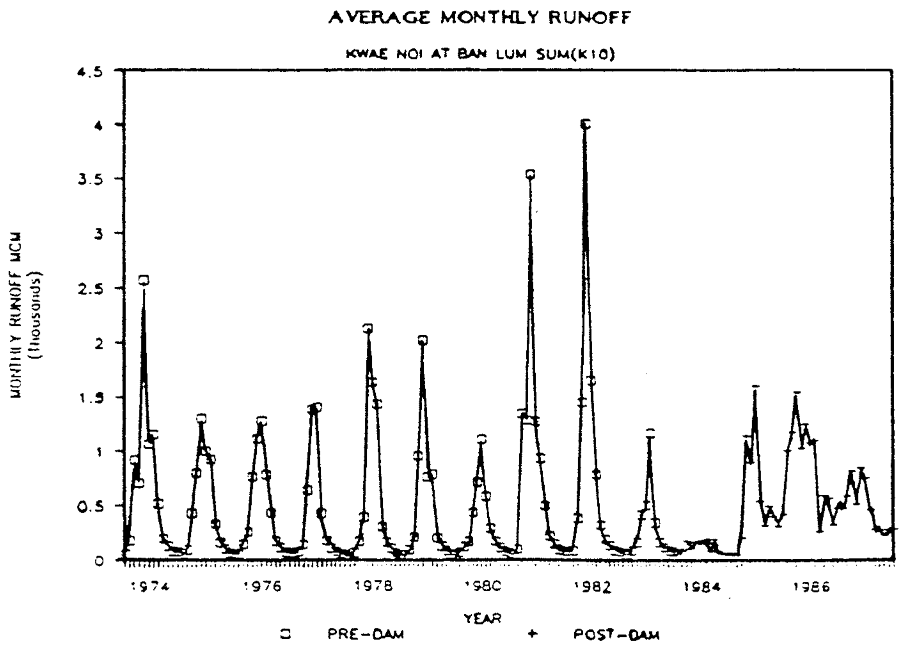


FIGURE 4-10

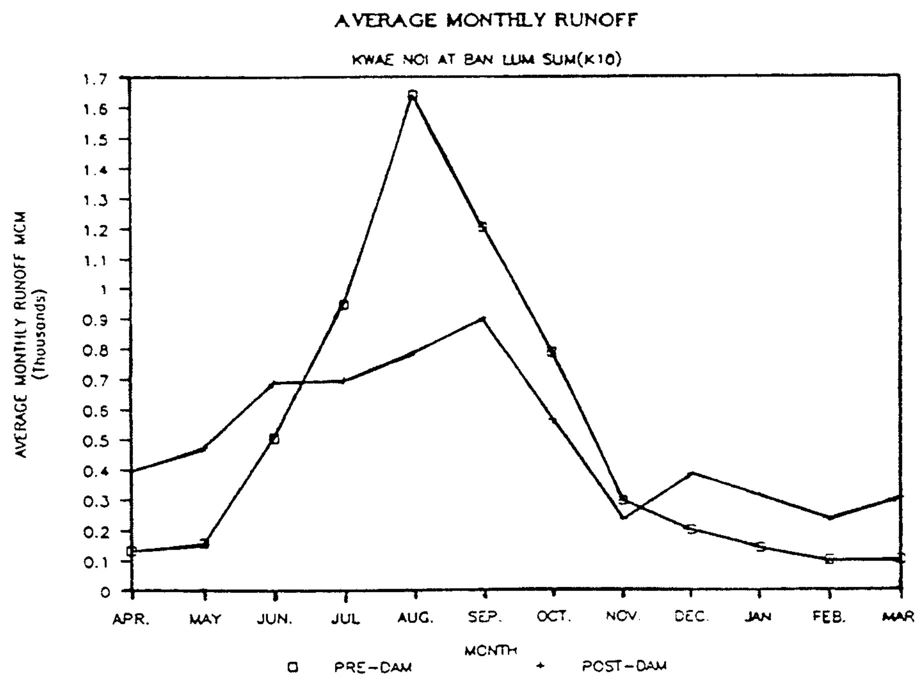


FIGURE 4-11

FIGURE 4-10, 4-11 THE AVERAGE RUNOFF IN THE KWAE NOI RIVER BEFORE AND AFTER IMPOUNDMENT.

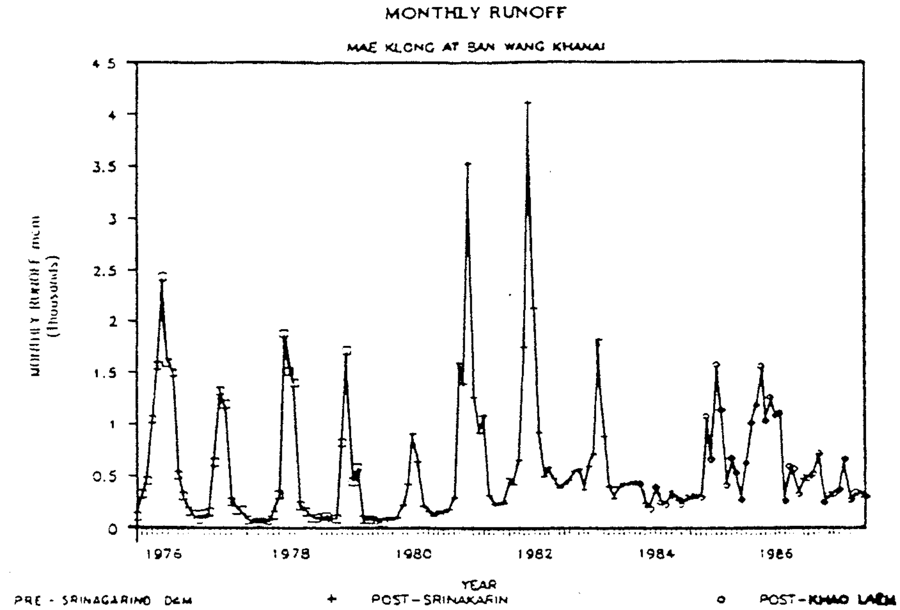


FIGURE 4-12

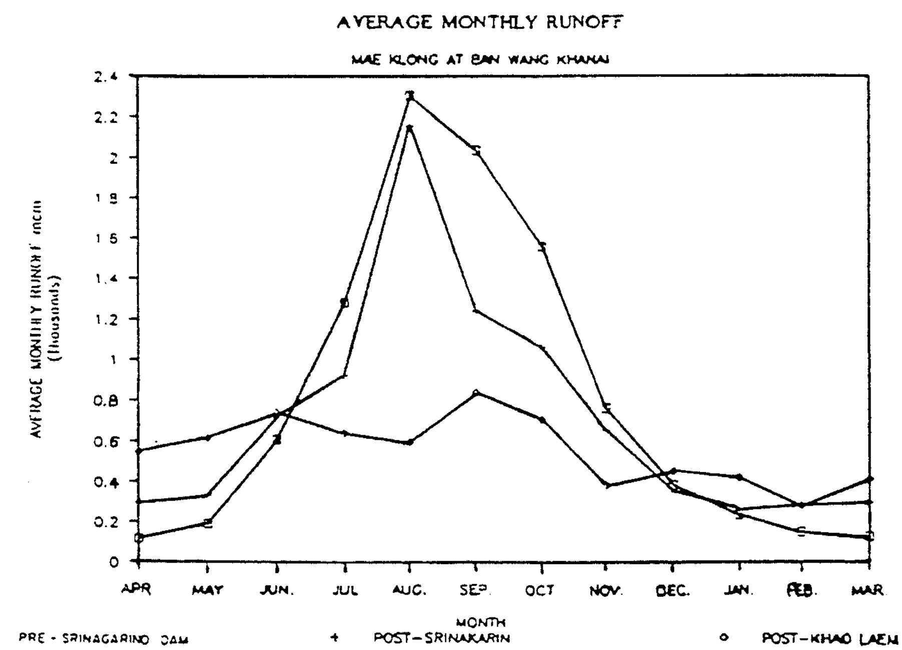


FIGURE 4-13

FIGURE 4-12, 4-13 THE AVERAGE RUNOFF IN THE MAE KLONG RIVER BEFORE AND AFTER THE CONSTRUCTION OF THE SRINAKARIN AND KHAO LAEM DAM.

In the Srinakarin reservoir, water was drawn from the aerated water zone. At present, no obnoxious odor of H_2S has been noticed in the releases from the reservoir (Team Consulting Engineers Co.,Ltd. 1980), but, Post Environmental Evaluation studied by SEATEC and NIDA (1987) argued that water discharged from the Srinakarin reservoir is taken from the anaerobic hypolimnion zone resulting in low DO levels and high CO_2 downstream.

4.3.2.3 Aquatic Biology and Fisheries

Some important fish species which used to exist in the river downstream, disappeared because they cannot migrate to upstream spawning sites in the river. The fish species which have been lost are Catlocapio siamensis, Tor spp., Labeo spp., Barilius spp., and Datnioides microlepis (Duangsawasdi 1989). The standing crop of fish downstream has been reduced from an average of 10.4 kg/rai (65 kg/ha) to 6.6 kg/rai (41.25 kg/ha). Effects of water pollution on fish populations in this stretch can also be expected, but, because of suitable habitats, benthic populations in the river section a few km downstream from the dam are relatively abundant.

4.3.3 Thermal Stratification

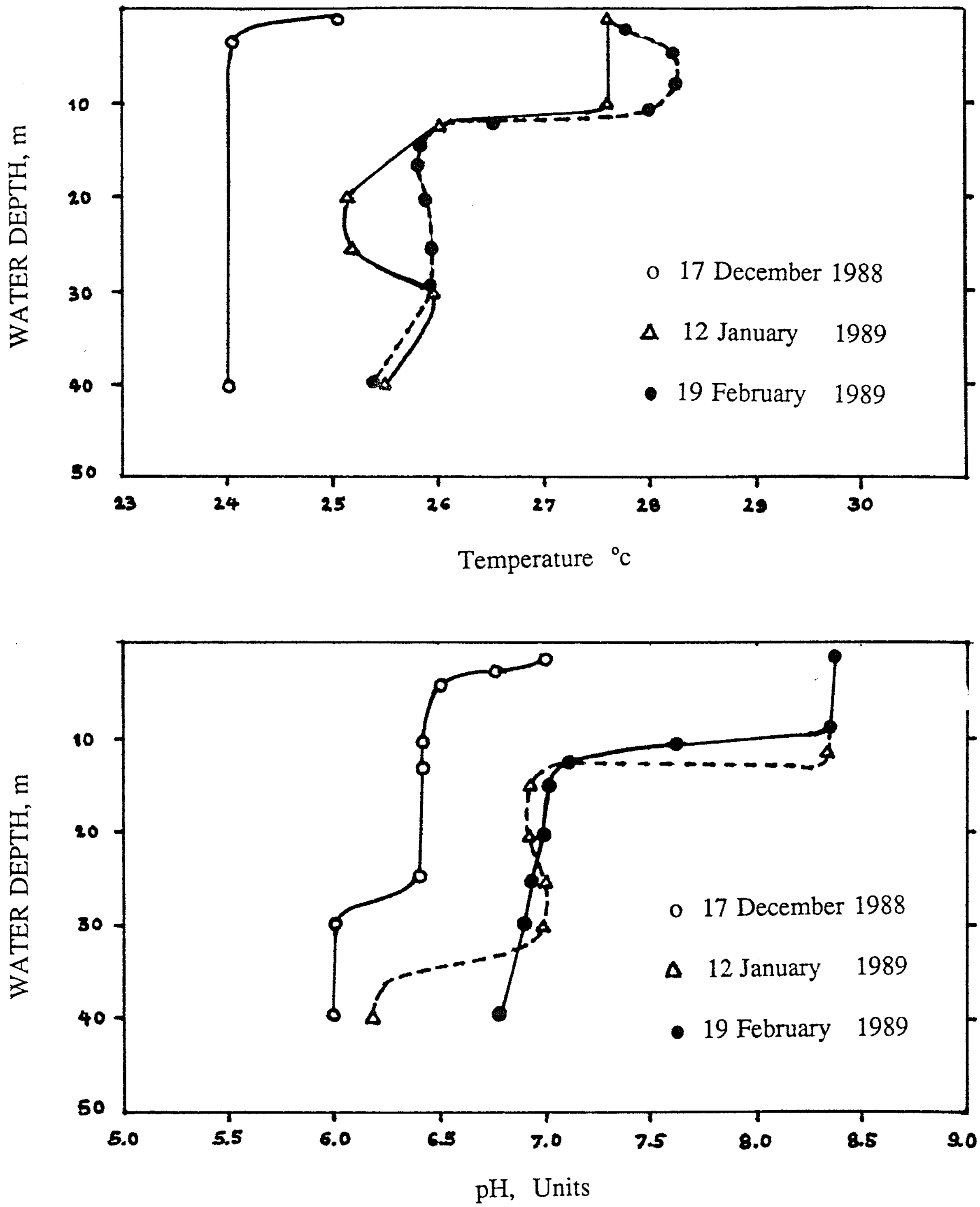
The Khao Laem reservoir is relatively deep with strong thermal stratification during most periods of the year. In summer (April 1989), the surface water temperature was above 30°C while the temperature below 10 m dropped to 26-27°C and remained stable at depths below 20 m. (Fig. 4-16a)(Pal Consultant Co.,Ltd. and Aggie Consult Co.,Ltd. 1990). Dissolved oxygen levels also declined from 7 mg/l to less than 1.0 mg/l at 5-10 m. DO decreased to 0 mg/l below 20 m in April (Fig. 4-17b). The evidence of deoxygenation in fig. 4-16b and high carbon dioxide in fig. 4-16a could be serious problems with low oxygen, high CH_4 and H_2S if discharge is from below 5 m in April.

In winter (December 1988), there were small differences between temperature in the surface and bottom layers of the reservoir (24.0-25.8°C). Temperature was stable at water depths below 2.5 m (Fig. 4-14a) and temperature in the top layer was only 1-2°C different from the lower layer. There were evidences of a high degree of mixing between bottom and top layers as shown by relatively low DO content and the high CO_2 level in the surface water because the effects of anaerobic conditions near the bottom had been brought to the surface (Fig 4-15). DO content dropped to 4-5 mg/l and CO_2 level increased to 4 mg/l in the surface water. Moreover, DO content was almost uniform from the surface water to 25-30 m before it declined significantly.

Thermal stratification was absent for very short period during cold weather which occurs between November and December. In January and February 1989, the top and bottom water layers began to be separated by differences in temperature, DO content, CO_2 level and pH (Fig. 4-14,4-15). In February, the DO content dropped to less than 1 mg/l at a water depth between 9 and 11 m, while CO_2 and H_2S concentration increased to 36 mg/l at a depth of 30 m.

A brief reservoir overturn in winter probably occurs during the period November to December. Poor quality water is replaced in the bottom layer by inflow water which has the same temperature and density. Inflowing water usually finds a depth which has water of the same density, therefore, in winter, inflowing water with lower temperature and higher density than reservoir surface water will go down to a lower water layer resulting in water circulation. In hot season, inflow water from the main tributaries probably have the same temperature as the top layer water. The overturn, therefore, could not occur because the influent water could not penetrate to the bottom and, therefore, replacement is impossible. Evidence for circulation and stratification in the Khao Laem reservoir can be deduced from data in figure 4-14 and 4-15. In December 1988, water circulation induced by strong winds in the reservoir area could result in mixing in the reservoir. Water temperatures are uniform from surface to bottom and pH values decreased probably because H_2S was brought up and mixed with oxygenated surface water producing H_2SO_4 (Cole 1983). DO and CO_2 also show evidence for circulation. DO levels are reduced, CO_2 concentrations go up in surface water and finally released into the atmosphere. At depth below 30 m, the CO_2 increase may be because circulation is incomplete caused by narrow bottom of the reservoir. In January and February 1989, stratification began and differences in water quality appeared in the surface layer. Water temperature increased and pH decreased. Decreasing temperature and pH were noted at a depth 10 m. In April 1989, stratification was very pronounced. Water quality at station 5, located at the upper end of the reservoir, was lower than water quality at station 1 and 2 which are located near the main tributary (Huai Pilok). (Figure 4-18) Figure 4-16, 4-17 show differences in water quality among these three stations. Water quality at station 5 was lowest, probably because it was contaminated by inflow from Sangkhla Buri municipality. This water could not mix because it entered a restricted area of the reservoir.

In the Srinakarin reservoir stratification also occurred as shown in figure 4-19. Water quality in the Srinakarin reservoir was better than in the Khao Laem reservoir. DO level in the upper layer was 6-7.5 mg/l, but declined to 0 mg/l at depth below 20 m. There was no CO_2 and H_2S existed at depth between 0 and 13 m in all season, therefore, discharge water should be taken 15 m below the surface to maintain downstream water quality.



<u>FIGURE 4-14</u> VARIATIONS OF TEMPERATURE AND pH CONTENTS WITH RESERVOIR WATER DEPTH, AT STATION 1 (KHAO LAEM RESERVOIR)

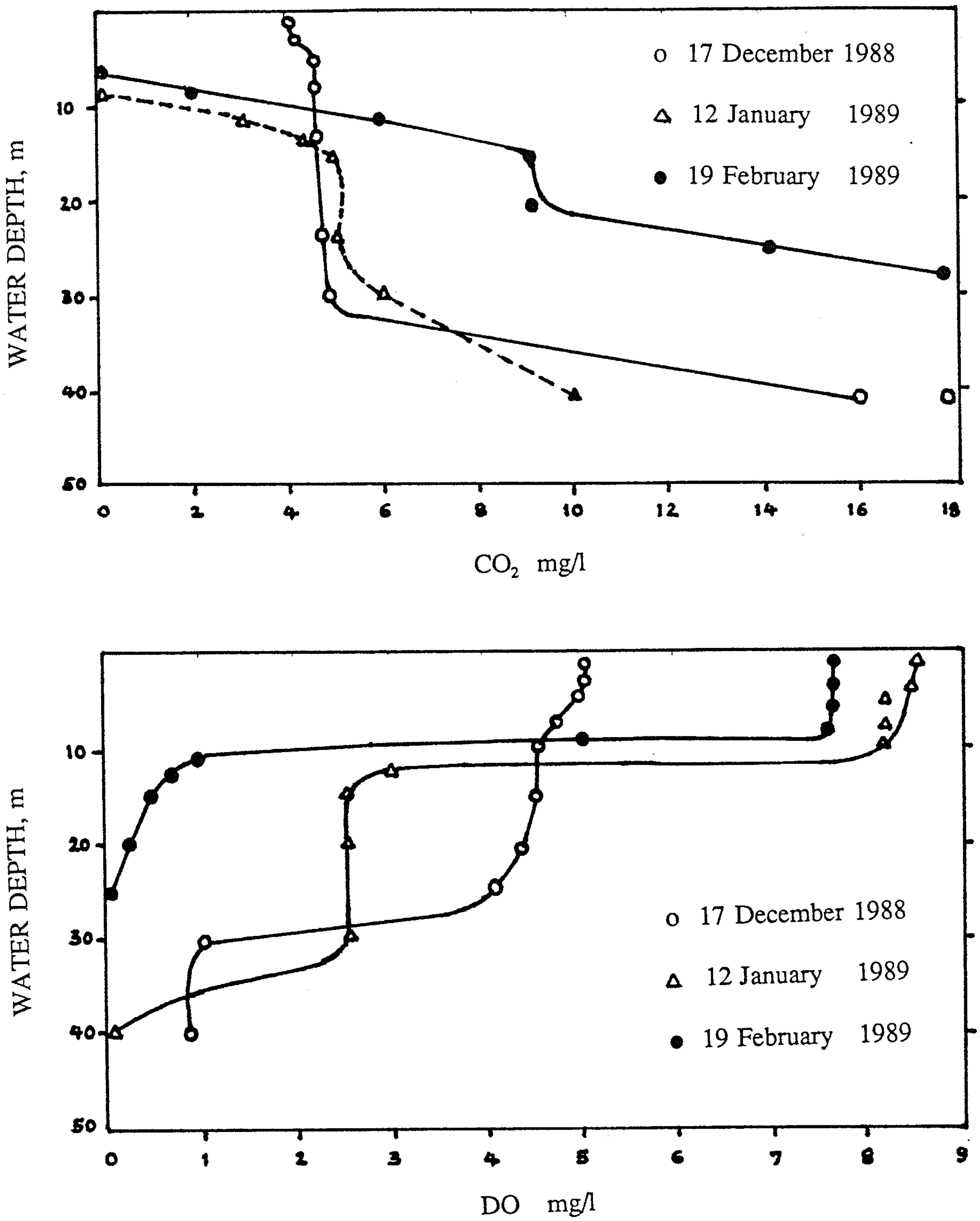
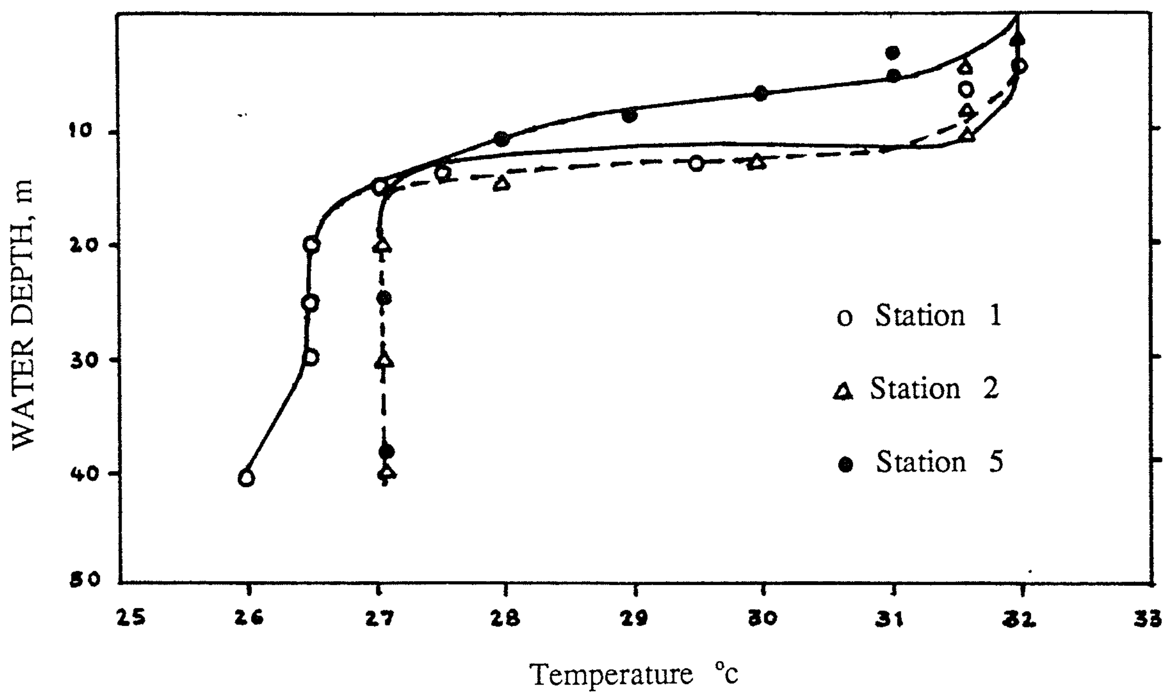
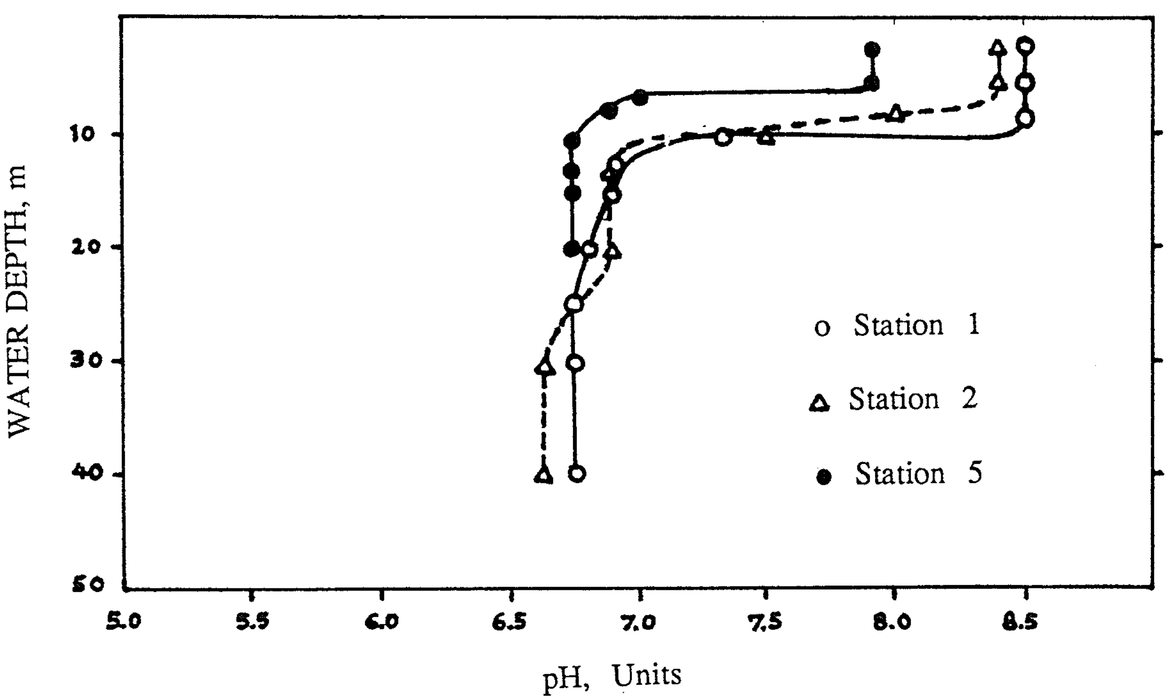
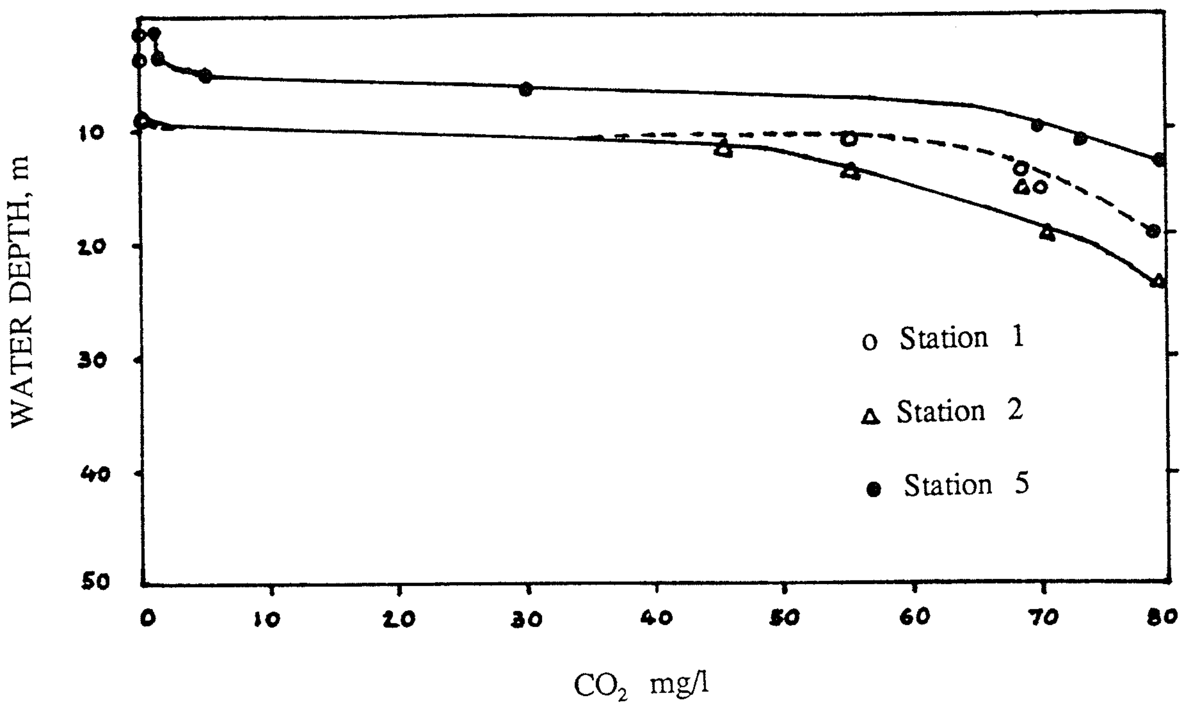


FIGURE 4-15 **VARIATIONS OF DO AND CO_2 CONTENTS WITH RESERVOIR WATER DEPTH, AT STATION 1 (KHAO LAEM RESERVOIR)**





<u>FIGURE 4-16</u> VARIATIONS OF TEMPERATURE AND pH CONTENTS WITH RESERVOIR WATER DEPTH (APRIL 1989, KHAO LAEM RESERVOIR)



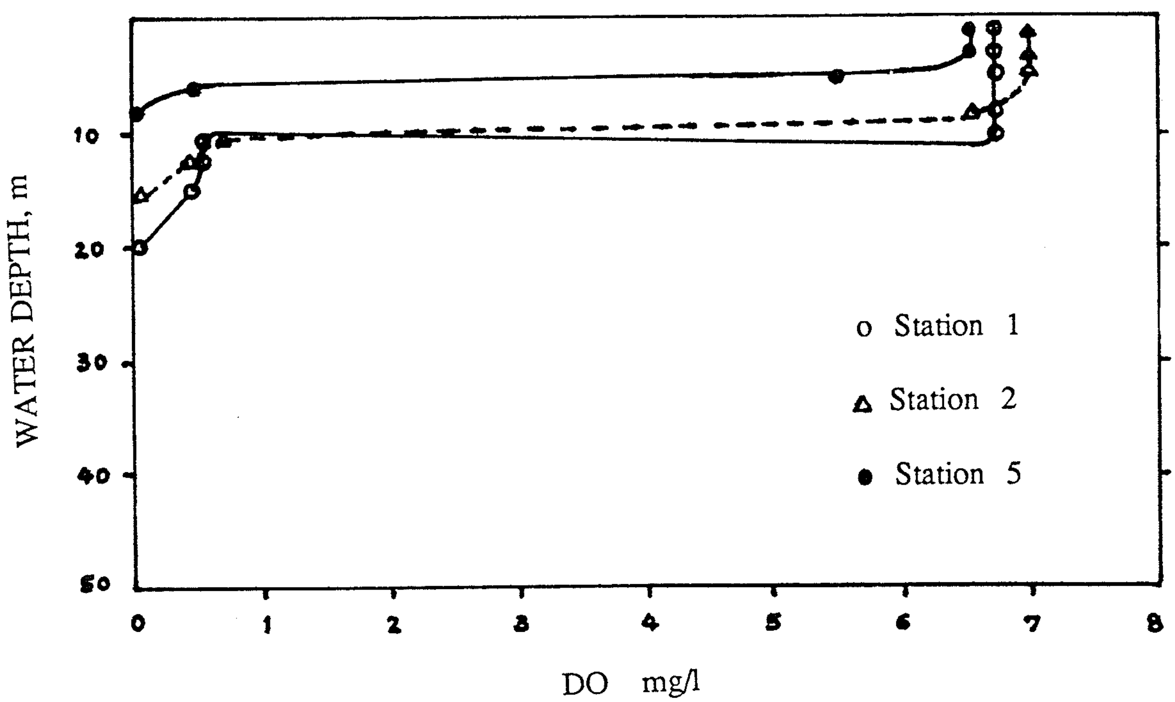


FIGURE 4-17 **VARIATIONS OF DO AND CO_2 CONTENTS WITH RESERVOIR WATER DEPTH (APRIL 1989, KHAO LAEM RESERVOIR)**

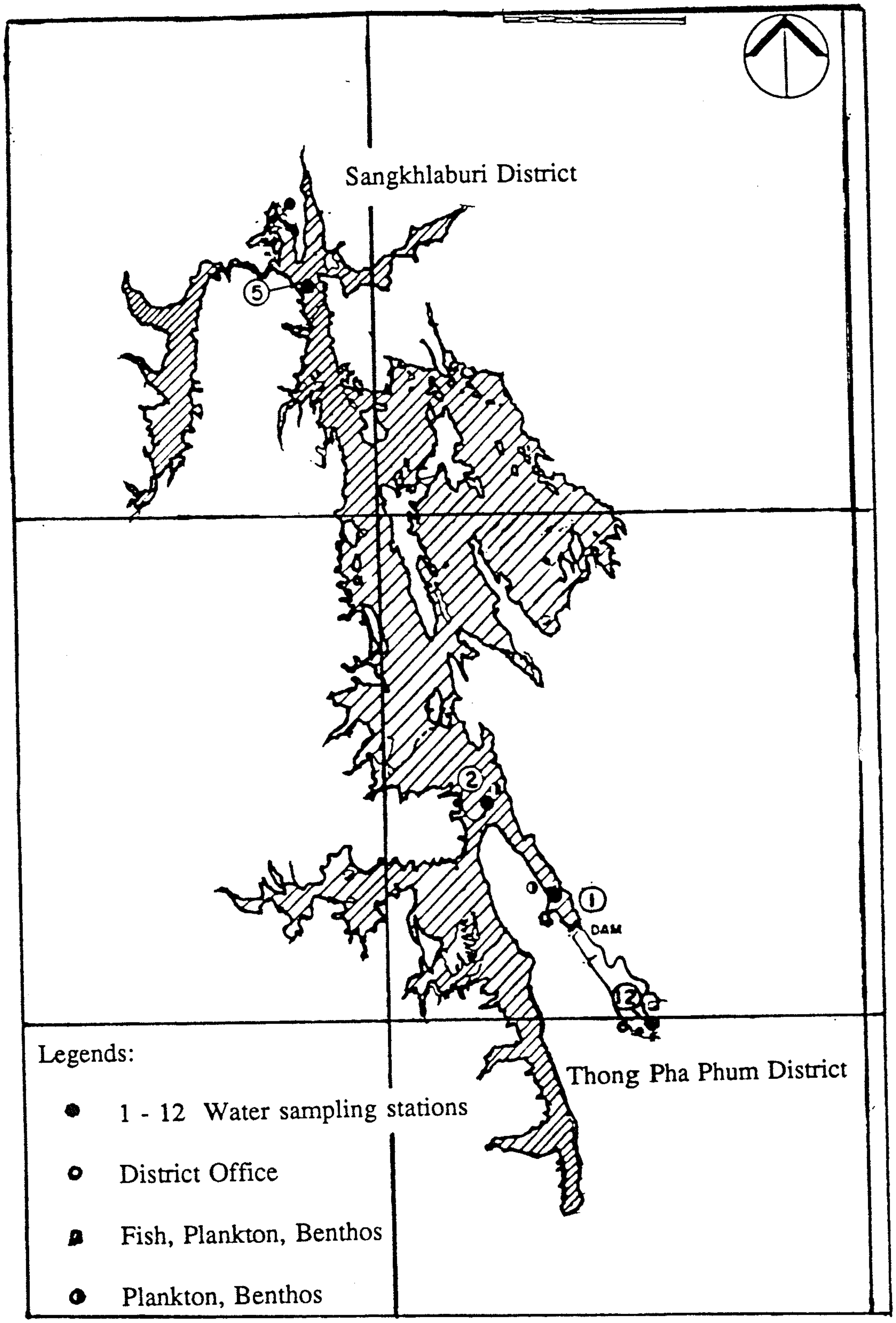


FIGURE 4-18 **WATER SAMPLING STATIONS IN THE KHAO LAEM RESERVOIR**

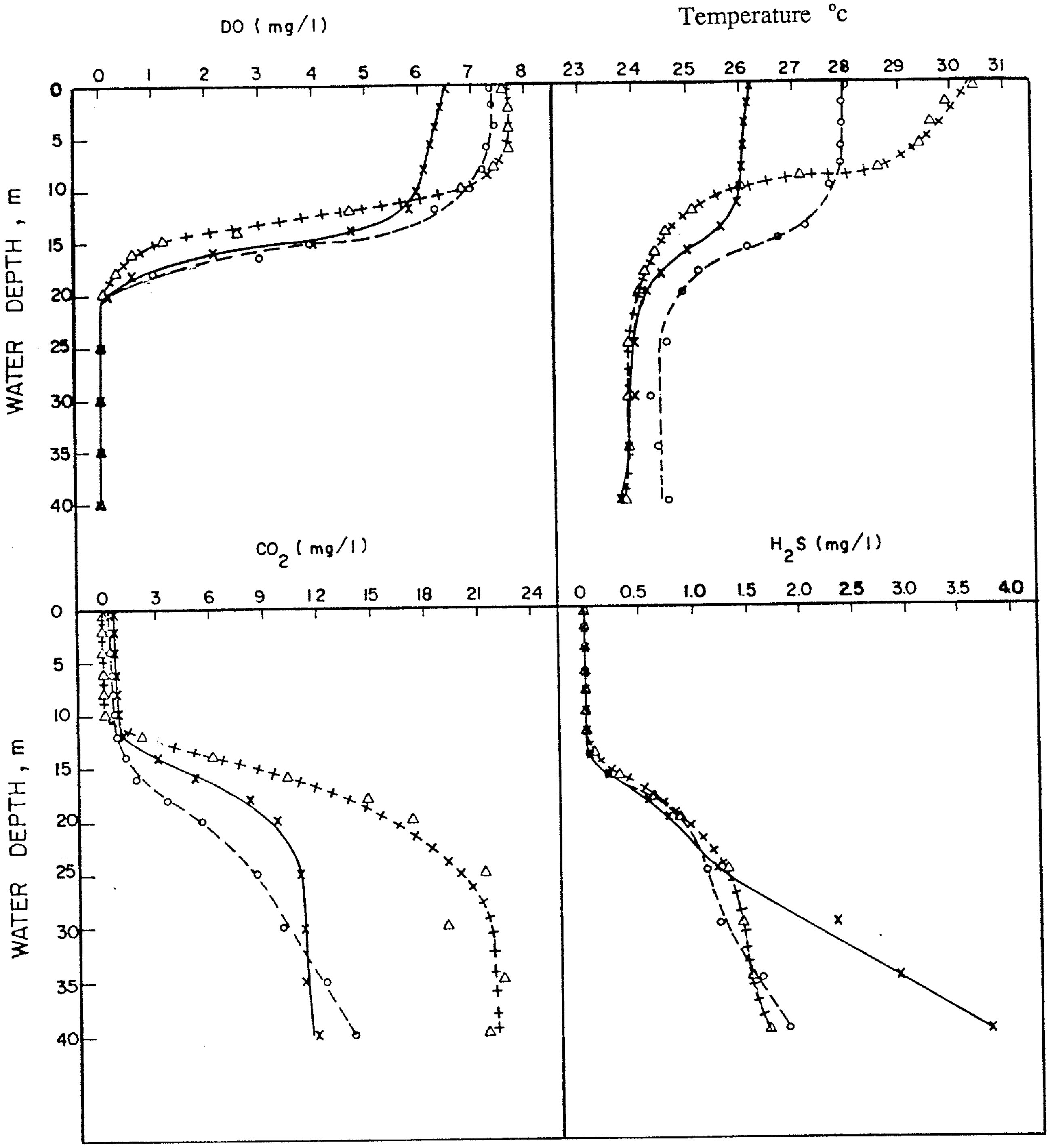


FIGURE 4-19 VARIATIONS OF WATER QUALITY WITH RESERVOIR WATER DEPTH (SRINAKARIN RESERVOIR)

LEGENDS			
	O----O----O----O	AUGUST	1986
	X——X——X——X	DECEMBER	1986
	Δ+++Δ+++Δ+++Δ	APRIL	1987

Table 4-5 Inflow water temperature and water temperature in the Srinakarin reservoir during August 1986 to April 1987.

Location	Level	Temperature		
		Aug 86	Dec 86	Apr 87
Upstream of the reservoir (inflow water)	Surface Bottom	23.5 23.7	21.4 21.4	30.0 30.0
Srinakarin Reservoir.	0.5 5.0 40.0	28.4 28.4 24.7	26.5 26.2 23.8	30.4 29.3 25.1

(SEATEC and NIDA 1987)

Data from table 4-5 could be used to predict overturn in the reservoir in August and December but the situation could not occur in the hot season. Inflow water has different temperature during different season as well as water temperature in the Srinakarin reservoir. In cold season inflow water can penetrate to the bottom because its temperature lower than water temperature at the bottom of the reservoir (21.4 and 23.8), but in hot season, inflow water temperature is as same as temperature at the surface of the reservoir (30.0 and 30.4), thus, it will find a depth that has the same density or same temperature which is the surface layer.

More studies should be undertaken to obtain additional information on the temperature of seasonal water inflows and on seasonal reservoir temperature profiles. This information would help to predict the impacts of inflow water on the reservoir conditions. Finally, this information could be used to recommend a water management scheme for the reservoir and could also indicate ways to improve downstream water quality. One recommendation might be to suggest an appropriate level for the turbine intake.

4.4 Consequences of the Nam Choan Hydroelectric Project

The Upper Kwae Yai basin is in the monsoonal area. The southwest monsoonal season may extend from June to October (Team Consulting Engineers Co.,Ltd. 1980). The basin average annual rainfall has been estimated at about 1,180 mm. Temperatures have been reported for different seasons. During the rainy season, air temperatures vary from 20°C to 35°C and in the cold season (November to February) they range from 7°C to 39°C. During the hot season, the maximum air temperature may be higher than 40°C. Relative humidity is generally constant throughout the year, and the monthly mean values vary between 60 and 75 percent (Team Consulting Engineers Co.,Ltd. 1980).

With the implementation and operation of the Upper Kwae Yai project (The Nam Choan Project), some environmental impacts may occur. The expected changes in the Upper Kwae Yai project reported by Team Consulting Engineers Co.,Ltd. 1980 are:

4.4.1 Climatological Conditions

The existing three reservoirs in the area, combined with the proposed Nam Choan project, could affect the regional humidity, temperatures and rainfall regimes. The total loss from evaporation caused by the Nam Choan, Srinakarin and Khao Laem reservoirs would be about 311 MCM or about 2.6 percent of the total runoff in the Mae Klong basin.

4.4.2 Surface Water Hydrology

4.4.2.1 Free-flowing stream will be replaced by a standing water body in the Nam Choan reservoir with the surface of 137 km^2.

4.4.2.2 Available drawdown of 8 m will be created in an average reservoir depth of 43.4 m (Chansawang et al 1986).

4.4.2.3 Insignificant losses of water by evaporation are anticipated.

4.4.2.4 Power production at the downstream reservoir would be reduced by about 1,650 MWh during the fill-up period, but afterwards the increases in power production from the Srinakarin powerhouse would be possible.

4.4.2.5 Inflow pattern of the Srinakarin reservoir would be altered significantly from one with large seasonal fluctuations to relative uniformity throughout the year. With flow regulation at the upper dams, the maximum storage of the Srinakarin reservoir required for regulation of inflows would be reduced by an estimated 44 percent.

4.4.3 Surface Water Quality

4.4.3.1 In the Srinakarin reservoir, the lowest observed DO content was about 3 to 5 mg/l, but CO_2 and nutrients were high in the surface water layer because of the decomposition of organic matter near the reservoir bottom and then turned to the surface layer by reservoir turnover occurring during the cold months.

The impoundment has caused a reduction of hardness of about 15 percent and some reductions of iron and manganese concentrations caused by sedimentation and/or precipitation. Concentrations of nitrates at the surface and mid-depth were sometimes very high, but phosphates were low. Lead were sometimes found, with concentrations above the maximum acceptable limits for drinking water. Hexa-valent Chromium, Mercury and Zinc were sometimes above the recommended threshold limits for aquatic organisms.

4.4.3.2 Water quality between the Nam Choan and Thi Khong damsites are similar to those found in the Srinakarin reservoir. The main differences from those of the Srinakarin reservoir water include:

(i) Lower transparency;

(ii) slightly higher iron and manganese concentrations;

(iii) slightly higher pH and alkalinity;

(iv) higher hardness (about 15%) than in the impounded water.

4.4.3.3 Stable thermal stratification is expected to occur during most of the year. Stratification would become less stable in the cold season. Reservoir turnover caused by inflowing water replacement in the bottom layer will occur in cold season as it occurs in the Srinakarin reservoir, but mixing of the water layer may be different, depending on temperature profiles and the morphometrical characteristics of the Nam Choan reservoir. A result of anaerobic decomposition at the reservoir bottom will be the low concentrations or virtual depletion of DO below a depth of about 20 m in the hot season. Consequently, the discharge level necessary to maintain water quality downstream should be 20 m from the surface. Since the release of nutrients from the flooded vegetation and soils in the areas included in the reservoir's drawdown zone and the return of nutrients from the bottom zone will occur, primary productivity in the reservoir during the first 4 to 5 years after impoundment will probably be higher than in the reservoir inflows.

4.4.3.4 Sediment entrapment in the Nam Choan reservoir will reduce nutrients in the Srinakarin and the Lower Kwae Yai reservoirs although some fraction of the total will be discharged in water released from the reservoir.

4.4.4 Ecological Resources

Plankton in the Srinakarin reservoir are higher during post-impoundment period because of the greater nutrient concentration. In the vicinity of the two proposed damsites, average plankton abundance observed in February 1980 was about 99,300 cell/m^3 of which more than 99.5 percent were phytoplankton.

Benthic populations in the Nam Choan reservoir were expected to be less diverse. Furthermore, changes in the composition of the plankton community were expected. Changes in flow regimes, bottom habitats and nutrient status are the main factors that may change benthic populations. These population may be restricted to aerated zones along the shoreline.

CHAPTER 5

FISH SPECIES IN THE KWAE YAI RIVER BASIN

This chapter is the study of fish species in the Kwae Yai River Basin before and after impoundment. From table 5-1, the fish species can be divided in four groups i.e.

1. Carp	51.00 %
2. Catfish	11.26 %
3. Murrel	12.39 %
4. Others	25.35 %
Total production	100.00 %

The average percentage of fish production during three year period (1968-1970)(NIFI 1985) were obtained from a survey done in the Kwae Yai river reach of Srisawat district which became the Srinakarin reservoir in 1980.

Table 5-1 The important fish species in the Kwae Yai river

Number	Scientific Name	Common Name
1	Leptobarbus hoevenii	Hoeven's slender carp
2	Hampala macrolepidota	Transverse-bar-barb
3	Hampala dispar	Eye-spot barb
4	Catlocarpio siamensis	-
5	Tor tembroides	Greater brook carp
6	Tor soro	Soro brook carp
7	Cyclocheilichthys apogon	Indian river barb
8	Cyclocheilichthys armatus	-
9	Cyclocheilichthys enoplos	Soldier river barb
10	Probarbus jullieni	Jullien's golden-price carp

Table 5-1 (Cont.)

Number	Scientific Name	Common Name
11	Cirrhinus jullieni	Jullien's mud carp
12	Cirrhinus microlepis	Small scale mud carp
13	Puntius daruphani	Golden belly barb
14	Puntius gonionotus	Common silver barb
15	Puntius orphoides	–
16	Puntioplites proctozysron	Smith barb
17	Osteochilus hasseltii	Barb
18	Osteochilus vitatus	–
19	Osteochilus spilopleura	–
20	Labiobarbus lineatus	–
21	Barbichthys laevis	Golden carp
22	Morulius chrysophekadion	Greater black shark
23	Wallagonia attu	Great white sheatfish
24	Ompok bimaculatus	–
25	Kryptopterus cryptopterus	Sheatfish
26	Kryptopterus bicirrhis	Sheatfish
27	Clarias batrachus	Batrachian walking catfish
28	Mystus vitatus	Iridescent mystus
29	Mystus nemurus	Yellow mystus
30	Mystus cavasius	Long-fatty finned mystus
31	Anabas testudineus	Common climbing perch
32	Osphronemus goramy	Giant gourami
33	Ophicephalus marulius	Great snake-head
34	Ophicephalus striatus	Striped snake-head
35	Ophicephalus micropeltes	Giant snake-head
36	Notopterus chitala	Spotted featherback
37	Notopterus notopterus	Grey featherback
38	Datniodes microlepis	Siamese tiger fish
39	Pristolepis fasciatus	Striped tiger nandid
40	Oxyeleotris marmoratus	Sand goby
41	Mastocembelus armatus	Armed spiny eel
42	Cyclocheilichthys repasson	-

(Sidthimunka 1972 and Duangsawasdi 1989)

Table 5-2 The fish species in Srinakarin reservoir after impoundment

Number	Scientific Name	Common Name
1.	Paralubuca riveroi	–
2.	Osteochilus hasselti	Hasselt's bony lipped barb
3.	Hampala macrolepidota	Transverse-bar-barb
4.	Noemacheilus masyae	-
5.	Osphronemus goramy	Giant gourami
6.	Ophicephalus striatus	Striped snake-head
7.	Ophicephalus micropeltes	Giant snake-head
8.	Ophicephalus gachua	Red-tailed snakehead
9.	Ophicephalus marulius	Great snake-head
10.	Tetraodon leiurus	Green pufferfish
11.	Notopterus chitala	Spotted featherback
12.	Notopterus notopterus	Grey featherback
13.	Mastacembelus armatus	Armed spiny eel
14.	Cyclocheilichthys repasson	-
15.	Puntius leiacanthus	Golden little barb
16.	Acanthopsis chororhynchos	-
17.	Clarias batrachus	Batrachian walking catfish
18.	Fluta alba	Swamp eel
19.	Chanda siamensis	Siamese glassfish
20.	Pristolepis fasciatus	Striped tiger nandid
21.	Macrognathus aculeatus	Spotted spiny eel
22.	Tetraodon leiurus	Green blowfish

(National Inland Fisheries Institute 1985)

Before impoundment, water in the Kwae Yai river contained a high level of dissolved oxygen. The river bed was sedimentary rock, limestone and dolomite, in the portion upstream from Srinakarin reservoir. In Srinakarin reservoir, the river bed used to be fine sand mixed with surface sediments (E.G.A.T. 1981 and Sidthimunka 1972). Fish living in the area use to migrated upstream and some species went out to inundated areas during the spawning season.

After impoundment, some physical and chemical conditions in the Nam Choan area would be changed. Hiranyawat (1988) predicted that some important conditions are expected to change. These are:

1. The velocity of running water will be reduced.

2. Impoundment will increase water depth.

3. The river bed containing rock and fine sand, suitable as spawning areas for some species will be converted to silt.

4. Oxygen concentrations in the water will decrease especially near the bottom of the reservoir. Moreover, hydrogen sulphide (H_2S), toxic to fish, may increase as a result of chemical reactions.

All of these effects will change fish species combination and relative abundance of species in the local fish community. Some fish will migrate to seek suitable conditions upstream and some fish may become the dominant species in the new reservoir because the new habitat favours their survival.

Table 5-2 shows fish species in Srinakarin reservoir during 1982 and 1983, recorded after impoundment (1980) and shows how economically important fish species declined after the formation of the Srinakarin reservoir (compare with table 5-1).

Economically Important Fish Species

According to data from table 5-1 and 5-2 and from the literature, the important fish species; either endangered species or those having an economic value, should be identified and their behaviour and life histories should be studied. The results could be used to explain population increases or decreases.

5.1 The important fish species in the Kwae Yai river

The fish species of the area can be divided into three groups according to their expected performance in the new environment.

1 Fish that are suitable for reservoir conditions.

1.1 Ophicephalus spp.	(Snake - head)
1.2 Clarias spp.	(Catfish)
1.3 Pristolepis fasciatus	(Striped tiger nandid)
1.4 Puntioplites proctozysron	(Smith barb)
1.5 Notopterus spp.	(Grey featherback)
1.6 Puntius spp.	(Common silver barb)
1.7 Ompok bimaculatus	(One spotted catfish)
1.8 Kryptopterus cryptopterus	(Sheatfish)

2 Fish that will need to adapt to live in the new conditions in the reservoir.

2.1 Hampala spp.	(Transverse-bar-barb)
2.2 Mystus spp.	(Yellow mystus)
2.3 Wallagonia attu	(Great white sheatfish)
2.4 Cirrhinus jullieni	(Jullien's mud carp)
2.5 Osteochilus spp.	(Hasselt's bony lipped barb)

3 Fish and aquatic animals that will disappear.

3.1 Catlocarpio siamensis (Giant carp)

3.2 Tor spp. (Brook carp)

3.3 Garra taeniata

3.4 Datniodes microlepis (Siamese tiger fish)

3.5 Probarbus jullieni (Jullien's golden-price carp)

3.6 Lobocheilus rhabdoura

3.7 Labiobarbus spilopleura (Barb)

3.8 Pelochelys bibroni (Kanburi giant softshell turtle)

5.2 Fish that are suitable for reservoir conditions.

Fish that will survive and increase in abundance in the reservoir have certain characteristics. Although oxygen concentration in the water is relatively low (3-5 mg/l) along with high concentration of carbon dioxide and nutrients (Team Consulting Engineers Co.,Ltd. 1980), some species can grow very well because they have special respiratory organ helping them to obtain enough oxygen. The fish in this group are:

5.2.1 Ophicephalus spp. and Clarias spp. (Snake-head and catfish)

These fish have special respiratory organs and they prefer still water to running water. They can find sufficient food by consuming small organisms which increased in population abundance as a result of the decomposition of organic matter. Catfish and Snake-head can eat both plants and animals. Moreover, catfish can also eat decomposed organism directly

(Ukataweewat 1978).

5.2.2 Pristolepis fasciatus (bleeker) or Striped tiger nandid

In the year 1978, there are 42 tons of *Pristolepis* were harvested from Srinakarin reservoir. The harvest increased significantly in the year 1979 (140 tons) which was the last year of the water storage period. The power station started its operation in 1980, however, the production of *Pristolepis* in 1978 was 69 % of total fish production from the reservoir, but production reduced to 27.37% of the total production in 1979 (Chansawang 1981). This decrease in their relative contribution indicates the increasing importance of other species in the reservoir. *Pristolepis* can be found in the rivers and reservoirs especially in the new reservoir where there are small trees which were left in the reservoir after the area was cleared for water storage purpose. In this area also found plenty of aquatic insects, insect larvae, zooplankton, small fish and shrimp which could be the food source of the fish (Chansawang 1981).

5.2.3 Puntioplites proctozysron (Smith barb)

Puntioplites grows well in reservoirs. They can be found among aquatic weeds near the shoreline where water depth is about 1 meter (Taksin 1986). Smith barb can eat both plants and animals. Their main food is plankton, organic detritus and insects (Banyen et al 1989), therefore, smith barb can be one of the dominant species in the new reservoir because of the high abundance of natural food resulting from the decomposition of dead plants and animals and the release of nutrients to the reservoir.

5.2.4 Notopterus spp. (Grey featherback)

Featherbacks can be found in shallow water. They live and spawn near a shoreline with small trees at an average depth from 4 to 6 meters. The fish usually feed on insect larvae, shrimp and aquatic weed near the water surface (Pupipat 1982). They will probably reproduce and grow rapidly in the new reservoir where there are trees near the shoreline. These areas could be both spawning and feeding zones.

5.2.5 Other fish

Many fish species such as Puntius, Ompok bimaculatus, Kryptopterus cryptopterus are able to live under reservoir conditions. Most of them can live in still water with low oxygen concentrations. They do not need special conditions for breeding and spawning, e.g. a rocky bed river and a high water flow. They can eat variety of foods existing in the reservoir.

According to Duangsawasdi (1989) found that in the Mae Klong River most of the species had a 1:1 sex ratio. She also demonstrated that neither males nor females had to migrate to meet the other sex for breeding upstream. Consequently, with this kind of life history, the impoundment will not affect fish species in terms of a migrating route obstruction. However, there are several species of fish that need to migrate upstream for spawning because they need high oxygen concentrations after the eggs hatch. These species will disappear from the river reach downstream from the dam.

5.3 Fish that will need to adapt to live in the new conditions in the reservoir.

There are some fish species whose physical characteristic are suitable primarily for a riverine habitat. After impoundment, the habitat will change but not so much as to affect their survival. They may be able to adapt to life as recessive species in the reservoir. These species are:

5.3.1 Hampala spp. (Transverse-bar-barb)

These fish prefer running water to still water, but they are also found in lakes and reservoirs where the water is clear and the bottom is rock or gravel. Barb usually live in submerged grass at a water depth of about 2.5 meters. They are carnivorous, feeding on small fish, insects, freshwater shrimp, worms and mussels. *Hampala* feed during the day. In this they differ from other fish carnivores (Pupipat et al 1986). Sukomol and Chantarapakdi (1980) reported that 7.2 % of the total production in Srinakarin reservoir in 1980 was *Hampala*. This report confirmed that *Hampala* can adapt to live successfully in reservoirs. Moreover, Ukataweewat (1980) reported that *Hampala* are cannibals; therefore they are not suitable for cage culture.

5.3.2 Mystus spp. (Yellow mystus)

Mystus live in rivers having a rocky bed or hard bottom surface and low water velocity. They can be found at depths from 2 to 40 meters (Leenanond 1981). *Mystus* is carnivore, feeding on fish, insects and freshwater shrimp (Leenanond 1981). This fish is another species that could survive and grow well in the reservoir although their natural habitat is running water and rivers with rocky beds.

5.3.3 Other fish

There are several fish species; e.g. Wallagonia attu, Cirrhinus jullieni, and Osteochilus spp that can also adapt to the reservoir habitat. These fish probably grow better if some corrective work is done to enhance the reservoir habitat to meet their needs. For example, by providing spawning areas, maintaining aquatic plants or small trees and also providing food which is appropriate for particular species.

5.4 Fish and aquatic animals that may disappear.

River impoundment will affect some species that require high oxygen concentrations, high water flow and specific spawning conditions. Changes in the water regime could cause these species to disappear. Fish that will be affected in this way after impoundment are:

5.4.1 Catlocarpio siamensis (Giant carp)

The Giant carp is one of the large carp living in the river. The biggest Giant carp that has been found was three meters long. The fish is herbivorous, feeding on phytoplankton, aquatic weed, and plant seed (Ukataweewat 1978).

After impoundment, Giant carp will move to upstream where there is running water and high oxygen concentration. The species have not be seen since the impoundment of the Srinakarin reservoir and the Vachilalongkorn irrigation dam, located downstream of the Srinakarin reservoir (Duangsawasdi 1989).

5.4.2 Tor spp., Garra taeniata, Datniodes microlepis, Probarbus jullieni

These fish have decreased in abundance by impoundments in the previously constructed projects. Most of them apparently moved to highly flow water upstream where the river bed is rock and gravel (Duangsawasdi 1989). Some of them still exist in the upper part of the Srinakarin reservoir; e.g. Tor tambroides, but they are rare. Most of these fish can swim in very fast flowing water. Their food is algae on rocks at the bottom of the river. They usually find their food near shore where water is not deep (1 meter) (Chansawang et al 1986).

5.4.3 Lobocheilus rhabdoura and Labiobarbus spilopleura (Barb)

These fish migrate upstream for spawning. They usually lay their eggs in rocky river beds where water velocity is high. After the eggs hatch, the larvae also need high oxygen concentrations; therefore, after impoundment, fish downstream from the dam will not be able to move upstream for spawning and the species will disappear (Chansawang et al 1986 and Chukajorn 1989).

5.4.4 Pelochelys bibroni (kanburi giant softshell turtle)

This species of turtle has been found only in the Kwae Yai river. They are the largest softshell turtle in the world. These turtles come onto the shore only when they are going to lay eggs. The only suitable sand shore, remaining after flooding in the Srinakarin reservoir, is in the Narasuan Wildlife Sanctuary which will be flooded by the Nam Choan project. If the project proceeds, the extinction of this softshell turtle is anticipated. (Tarnchalanukit and Hiranyawat 1988 and Chukajorn 1989).

5.5 Conclusion

Change of water quality in the Nam Choan project may alter fish populations living in the area, especially those species that need specific water conditions for eggs and their young. Erosion may cause low transparency reducing egg survival rate. Decreases in DO concentrations and increasing of CH_4 and H_2S could cause the reduction of fish species that are adapted to running and shallow water. Fish that feed on benthos may also show reduction in their populations because of declining of benthic population in the reservoir near the bottom layer.

However, overall, the fish populations in the new reservoir after impoundment will increase as a result of high nutrient concentrations received from the newly flooded areas. High nutrient levels will result in increase in plankton and aquatic plants. The abundance of plankton in the Khao Laem reservoir after impoundment, for example, has increased from 2,000 cells/m^3 to a maximum of 66 million cells/m^3 (Pal Consultants Co.,Ltd., and Aggie Consult Co.,Ltd., 1990). A great abundance of plankton and an increase in productivity will support rich populations of fish in the reservoir. Fish standing crop in the Khao Laem reservoir increased from 10.4 kg/rai (65 kg/ha) to an average 16.4 kg/rai (102.5 kg/ha) after impoundment. The fish standing crop in the Khao Laem reservoir is believed to be high for several years following impoundment (Pal Consultants Co.Ltd., and Aggie Consult Co.Ltd. 1990).

Fish standing crop in the river in the Nam Choan area is estimated to be 19.8 kg/rai (123.75 kg/ha)(Chansawang et al 1986). Fish production after impoundment is expected to increase because favourable conditions will occur, similar to those prevailing in the completed reservoirs in the system. Nutrient from top soil of newly flooded areas and decomposition of flooded vegetation will releases nutrients into the reservoir increasing the amount of plankton and benthos in the shallow water which are the primary food of some fish species. Standing timber, which would be left in the reservoir basin, will help protect fish from their enemies and also provide substrate for organisms on which the fish feed and also provide feeding areas for fish (Bhukaswan 1983 and Davis and Hughes 1971).

To maintain production near the optimal level, several management techniques have been practised in the reservoirs including the manipulation of the habitats, fish passage, provision of artificial spawning grounds, fish stocking etc. (Bhukaswan 1983). In the Nam Choan project, some fish species could be managed to maintain their populations and eventually increase fish production in the reservoir.

However, some fish and other animals such as softshell turtle which is an endanger species will not be able to survive in the project area.

CHAPTER 6

ELEVATED MERCURY LEVELS IN FISH RESULTING FROM NEWLY FLOODED RESERVOIR

6.1 Introduction

Elevated mercury levels in fish are often observed after flooding of soil and vegetation. Bacteria living in flooded soil probably transform mercury to methyl mercury at rates faster than in natural lakes. Aquatic organisms can take up this methyl mercury very quickly. Many physical, chemical, and biological conditions in Thai reservoirs are similar to those in the United States and Canada, for example, with respect to aerobic and anaerobic and pH conditions which could affect levels of mercury in fish. Temperatures in Thai reservoir are higher at approximately 20-30°c (Pawaputanon 1986). However, there is no relationship between environmental temperatures and mercury levels in fish, therefore, elevated mercury levels in fish caused by newly flooded reservoirs probably exist in Thai reservoirs. Because studies of elevated mercury concentrations in fish muscle from reservoirs resulting from bacterial methylation have not been done in Thailand, this study could be used to determine if the presence of mercury constitutes a problem in Thai reservoirs. The results will be useful for developing additional studies and could also help to set standards which would protect consumer's health from mercury contamination.

Mercury concentration in fish from Thai reservoirs

In Thailand, there are many newly built reservoirs designed to provide hydroelectric power or for irrigation purposes. These reservoirs flood large amounts of land which used to be both forested and agricultural areas. There are 18 major reservoirs which cover a total surface area of about 230,000 ha. Most of them are shallow and productive (Pawaputanon 1986). One major problem in the Thai reservoirs is soil erosion. However, reservoirs resulting from hydroelectric projects are relatively deep and have high concentrations of H_2S near the bottom. Thus, anaerobic bacterial methylation could not occur in sediment under conditions of high H_2S concentration (Canada-Manitoba Mercury Agreement 1987).

6.2 Methodology

Studies were done in areas which have no agricultural and industrial activities which are potential sources of anthropogenic mercury. Samples were collected from three locations:

a) A reservoir impounded five years ago (The Khao Laem Reservoir);

b) A reservoir impounded ten years ago (The Srinakarin Reservoir);

c) The area that was proposed for the new Nam Choan Reservoir.

To determine mercury levels in fish from the three different locations, fish samples were collected from fishermen and from fish markets in each location. At the Nam Choan site, there are several rafts collecting fish from fishermen who catch fish in the section of river which is the proposed reservoir area. Four species of fish were collected. Fork lengths and round weights were measured before approximately 10 g of fish muscle was removed from each fish. These tissue sample were kept at low temperatures.

Fish samples from the Srinakarin and Khao Laem reservoirs were collected using the same methods. Five species were sampled from the Srinakarin reservoir and four from the Khao Laem reservoir. (Appendix 1)

Fish collected from the three locations differed in size and number. Some species were different because different species were available at each location, however, an attempt was made to ensure that fish from all sites were comparable in species and size.

Fish samples were tested to determine mercury levels at the Freshwater Institute, Department of Fisheries and Oceans, Winnipeg, Manitoba by using Cold Vapor Flameless Atomic Absorption Spectrophotometry (Hendzel and Jamieson 1976).(Raw data is presented in appendix 2). The data including fork length, round weight and mercury concentration were analyzed by using the following statistical analysis conducted with a Hewlett Packard 9836 Computer. Log_{10} fork length and log_{10}[Hg] from each fish species were analyzed using One Way Analysis of Covariance to determine whether differences in mercury concentration among the three different sites were statistically significant. Where significant different were indicated by Analysis of Covariance, Multiple Comparison tests (Duncan's Test and Least Significant Difference) were used to determine significant differences between sites.

Mean concentrations of muscle mercury for each fish species were reported as three values.

1. Arithmetic means

2. A standardized mean calculated from the linear regression of log mercury concentration on log fork length for each sample at a fixed fork length for each species (Appendix 3). The

following arbitrary fork lengths were utilized in calculating the standardized mean:

- 175 mm for *Pristolepis*
- 175 mm for *Puntioplites*
- 260 mm for *Hampala*
- 210 mm for *Morulius*

(Appendix 3) These lengths were chosen as approximations of the grand mean fork lengths for each species for the samples collected.

3. An adjusted mean predicted from the grand mean fork length by the within group linear regression of log mercury concentrations on log fork length in an analysis of covariance model (Appendix 4).

6.3 Results

The Srinakarin (Site 1) and Khoa Laem (Site 2) reservoirs have been flooded for ten and five years respectively. Methyl mercury concentrations in fish were expected to be higher than in the proposed Nam Choan area (Site 3). The result of Multiple Comparison at alpha level = 0.05 are shown in table (6-1)-(6-3)

Table (6-1) - (6-3) and Figure (6-1) - (6-3) show multiple comparisons for each fish species in different locations. Significant different in mercury levels among sites are shown by different letters i.e. a, b, and c.

Table 6-1 Pristolepis fasciatus

Duncan's Test

Error mean square	=	.0476
Degrees of freedom	=	49
Harmonic average sample size	=	16.9565
Alpha level	=	.05

Means Separated	Table Value	Required Difference
3	2.9965	.1587
2	2.8465	.1507

Multiple Comparison on Site

Level	Mean	Sample Size	Separation
3	-1.1227	20	a
2	-1.0578	13	ab
1	-.9456	20	b

Least Significant Difference

Error mean square	=	.0476
Degrees of freedom	=	49
Harmonic average sample size	=	16.9565
Alpha level	=	.05
Table value from student's t	=	2.0115
LSD value	=	.1506

Multiple Comparisons on Site

Level	Mean	Sample Size	Separation
3	-1.1227	20	a
2	-1.0578	13	ab
1	-.9456	20	b

MULTIPLE COMPARISON PLOT : LSD

Pristolepis fasciatus

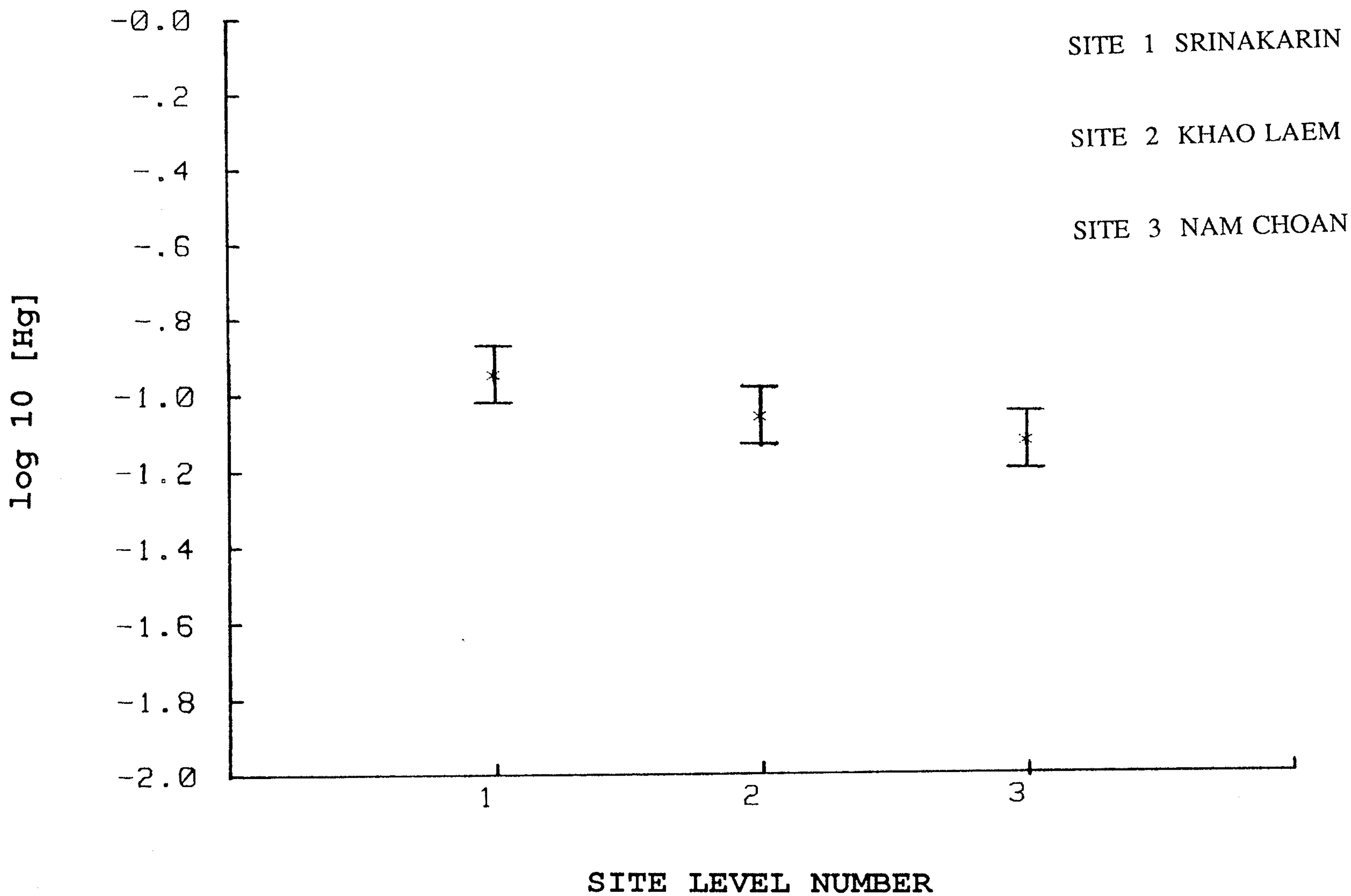


Table 6-2 Puntioplites proctozysron

Duncan's Test

Error mean square	=	.0433
Degrees of freedom	=	56
Harmonic average sample size	=	20.0000
Alpha level	=	.05

Means Separated	Table Value	Required Difference
3	2.9860	.1389
2	2.8360	.1320

Multiple Comparison on Site

Level	Mean	Sample Size	Separation
3	-1.8372	20	a
1	-1.3424	20	b
2	-1.1138	20	c

Least Significant Difference

Error mean square	=	.0433
Degrees of freedom	=	56
Harmonic average sample size	=	20.0000
Alpha level	=	.05
Table value from student's t	=	2.0042
LSD value	=	.1313

Multiple Comparison on Site

Level	Mean	Sample Size	Separation
3	-1.8372	20	a
1	-1.3424	20	b
2	-1.1138	20	c

MULTIPLE COMPARISON PLOT : LSD
<u>*Puntioplites proctozysron*</u>

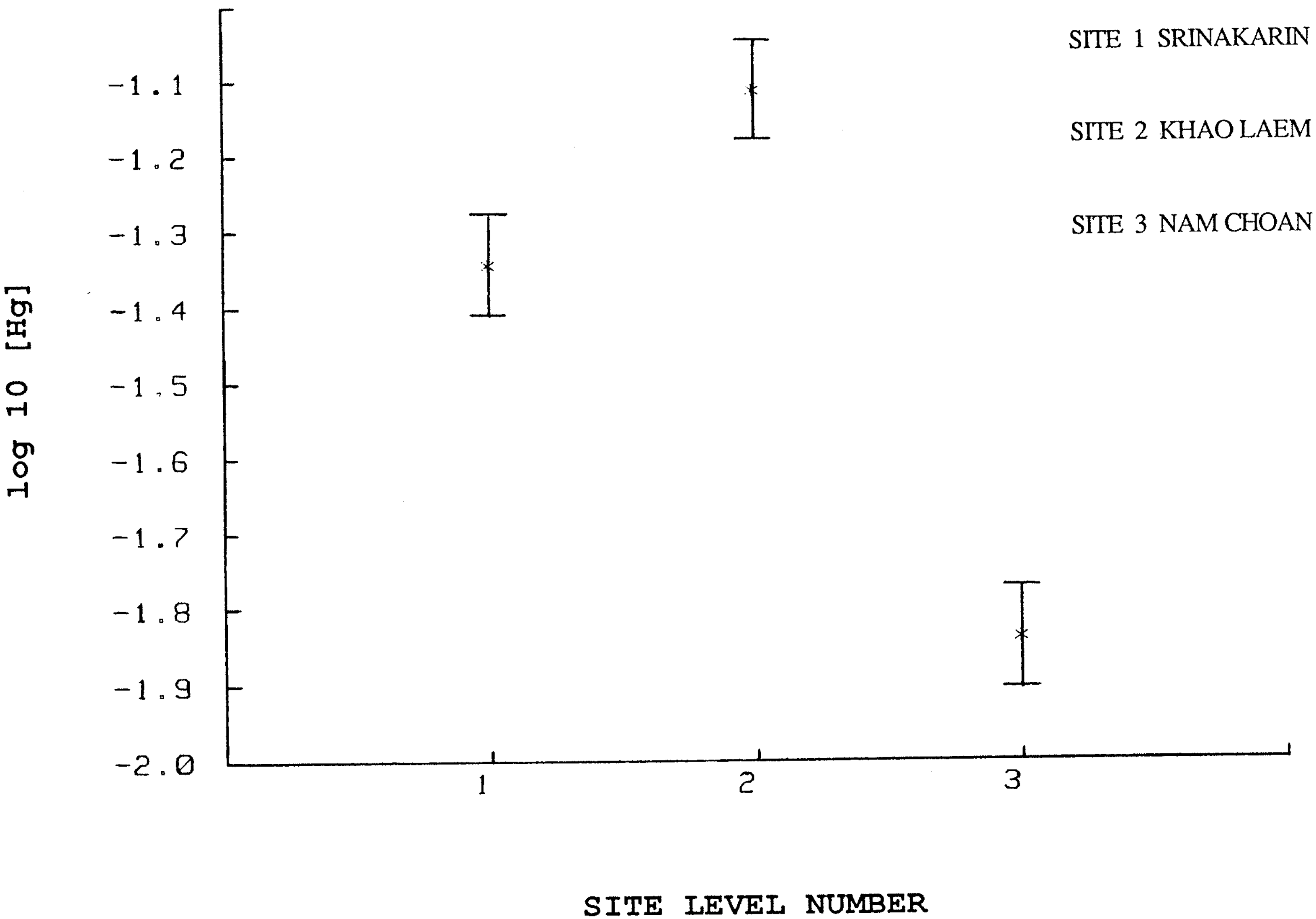


Table 6-3 Hampala macrolepidota

Duncan's Test

Error mean square	=	.0564
Degrees of freedom	=	37
Harmonic average sample size	=	20.0000
Alpha level	=	.05

Means Separated	Table Value	Required Difference
2	2.8690	.1524

Multiple Comparison on Site

Level	Mean	Sample Size	Separation
1	-.9377	20	a
2	-.4022	20	b

Least Significant Difference

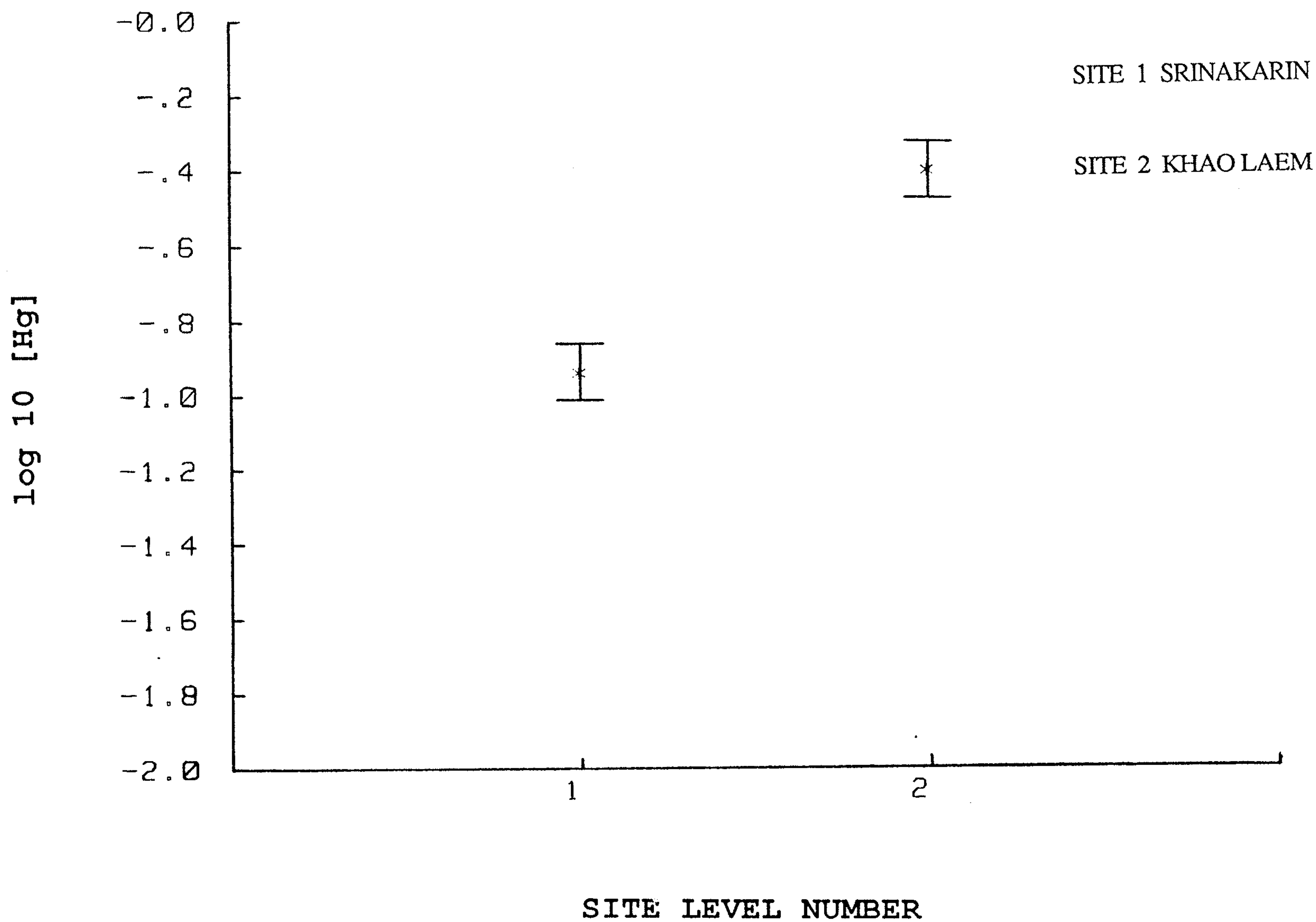
Error mean square	=	.0564
Degrees of freedom	=	37
Harmonic average sample size	=	20.0000
Alpha level	=	.05
Table value from student's t	=	2.0273
LSD value	=	.1523

Multiple Comparison on Site

Level	Mean	Sample Size	Separation
1	-.9377	20	a
2	-.4022	20	b

MULTIPLE COMPARISON PLOT : LSD

Hampala macrolepidota



Pristolepis fasciatus

Pristolepis is a herbivorous species. One Way Analysis of Covariance (Appendix 4) indicated that there was a statistically significant difference among the three sites sampled. Mercury concentrations ($\log_{10}$[Hg]) between site-1 (Srinakarin reservoir) and site-2 (Khao Laem reservoir) were not significantly different (Table 6-1, Fig. 6-1). Fish in the two reservoirs contain mercury in the same level. Mercury concentrations in Pristolepis from site-2 and site-3 (Nam Choan reservoir) were also not significantly different, however, levels of mercury in fish from site-1 was significantly greater than site-3, showing the effect of bacterial methylation due to impoundment.

Puntioplites proctozysron

This fish species can feed on both animals and aquatic plants. The result shows significantly different of mercury levels at all three locations (App. 4, Table 6-2, Fig. 6-2). Mercury levels in fish from the Khao Laem reservoir were highest and fish from the Nam Choan area contained the lowest mercury concentrations.

Hampala macrolepidota

Hampala is a predatory fish and they are also cannibals. The results of the analysis for mercury concentrations in the tissues of this fish species show that fish in the Khao Laem reservoir contained a higher mercury level than fish from the Srinakarin reservoir (App.4, Table 6-3, Fig. 6-3). The results are also similar to those of *Puntioplites* that fish in the Khao Laem Reservoir contained a higher mercury concentrations than fish from the Srinakarin Reservoir.

Morulius chrysophekadion

The results from One Way Analysis of Covariance (appendix 4) show that mercury levels were not significantly different between Srinakarin and Khao Laem reservoirs.

6.4 Discussion

Fish were compared between species and sites to determine mercury concentrations in their muscle tissue. The adjusted mean from grand mean fork length and mean standardized on log10 fork length for each species were determined, to adjust sample mean values which may have widely different fork length distributions. It is concluded that fish from newly flooded reservoirs had mercury levels higher than the undisturbed area. The amount of mercury in fish muscle may decline depending on the age of the reservoir, therefore, the amount of mercury in fish from the Srinakarin reservoir which is ten years old is lower than concentrations in fish from the Khao Laem reservoir which is only five years old. At the site of the proposed Nam Choan reservoir mercury levels in fish were low because the area is not flooded.

In the Khao Laem reservoir area, there are some mining activities which include mining for lead, zinc, and copper (Pal Consultants Co.,Ltd.,and Aggie Consult Co.,Ltd. 1990), however, there are no activities such as smelting of ores to extract metal that could result in mercury contamination in the reservoir. Therefore, elevated mercury in fish muscle are not cause from these mining activities.

Although the results show that *Pristolepis* at site 1 (Srinakarin) had highest mercury, the concentration was not significantly different from *Pristolepis* at site 2 (Khao Laem). This result may be different from what was expected. In general, the results obtained for other fish species confirmed that there are elevated mercury levels in newly flooded reservoirs.

Mercury levels in predatory fish are higher than herbivorous species. Appendix 3 shows the average of mercury levels between predatory fish i.e. *Pristolepis* and *Hampala* (0.09 and 0.21 ug/g [Hg]) and herbivorous species i.e. *Puntioplites* and *Morulius* (0.04 and 0.02 ug/g [Hg] respectively. Moreover, the declining of mercury levels in fish muscle may occur faster in tropical zones than in temperate zones, because decomposition rates of organic matter are higher in tropical regions.

Therefore, mercury levels in fish in the Nam Choan area can be expected to decline rapidly after impoundment especially in herbivorous species that consume plant and phytoplankton but in predatory fish higher mercury levels can be expected, particularly in the first year of the impoundment.

Mercury levels in fish from all sites were still lower than the maximum allowable standards for human consumption according to the Canadian and United States guidelines, however, impoundments in Thailand apparent caused increases in mercury levels in fish muscle which have been elevated higher in the first few years after impoundment. Soon after impoundment these levels probably exceeded standards for human consumption. Moreover, for people who eat fish on a regular basis, Canadian guidelines for mercury levels is 0.2 ppm which is lower than level for commercial sale (0.5 ppm). Consequently, further studies to be conducted in other reservoirs are required especially in shallow ones which would probably produce more methylmercury under aerobic conditions.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

In chapter 5 and 6, I showed that there are some significant changes in the existing reservoirs ie. the Srinakarin and Khao Laem reservoirs. Fish habitat was altered as a result of river impoundment. These habitat changes caused changes in fish communities. Some species are suitable for the new habitat and will increase in abundance while others will decrease and, perhaps, disappear. Mercury concentration in fish muscle will also increase significantly, but will be still maintained below the United States and Canadian standard for human consumption.

Some mitigation could be provided to minimize some of the environmental impacts which will occur in the proposed Nam Choan Project. Fish habitat could be improved to maintain fish populations and produce increases in fish production in the reservoir. Some regulations are also necessary for fish conservation. The following management techniques are recommended for fisheries management in the proposed reservoir:

1. Habitat manipulation

The impoundment areas may not be favourable habitat for fish, however, productivity could be significantly increased if physical and chemical conditions in the reservoir were improved. Trees need not be cleared. Many fish species would find that standing timber was a favourable habitat, providing them with food and shelter. Complete clearing could be done in certain area such as forebay of the dam.

Artificial spawning grounds should be provided for some species such as *Mystus*. They prefer to live in river with a rocky bed or other hard substrate in low velocity currents. The giant softshell turtle will only lay its eggs on suitable sand shore. An artificial sandy shore should be provided for them after the area is flooded.

2. Fish passage

Fish passage seem to be less needed in the tropics than in temperate regions because there are few truly anadromous fish (Bhukaswan 1983). Probarbus jullieni, however, do migrate upstream for spawning. Tor tambroides migrate downstream in the rainy season and return to spawn upstream on rocky substrate in running water (Department of Fisheries, Thailand 1987). Small minnow-like fish spawn mainly in newly flooded grasses and shrubs along the reservoir shoreline and in the floodplain (Bhukaswan 1983). Since fishways are expensive to build and operate, they, therefore, are not considered necessary for the Nam Choan project because the obstruction in a stream does not cause a serious decline or extinction of commercial fish species (Some species may have disappeared already as a consequence of former downstream projects), however, if necessary, a fish transportation system could be provided using suitable transportation trucks.

3. Fish stocking

A fish stocking program could help maintain populations of non reproducing fish by introducing into the reservoir such fish as Chinese carp or fish that need to migrate for upstream spawning; for example, Probarbus jullieni. The introduction of exotic or foreign species should be controlled and carefully studied. The consequences of any introductions of new species, their ability to adapt to living under new conditions, their capability to reproduce in the reservoir, their growth rate and their interactions with native species should be evaluated. Introduced species should not only have a good growth rate, but be compatible in the new environment with other fish species (Bhukaswan and Pholprasith 1976). There are a number of valuable fish which could be introduced into reservoirs. These are Rohu (*Labeo rohita*), *Cirrhinus mrigala*, *Cyprinus carpio*, *Tilapia spp*. and chinese carp (Bhukaswan 1983).

4. Regulation of the fisheries

The purpose of fishery regulations is to ensure a high but sustainable yield to the fisheries (Bhukaswan 1983). To achieve this purpose, it is necessary to have some regulations such as closed areas and closed seasons. Fishing should be prohibited in the main spawning grounds during spawning periods (May 16th to September 15th.) Fishing gear and fishing methods should be controlled by limiting mesh size and prohibiting the use of damaging methods; e.g., poisons, explosives and electrical shocking.

5. Management of water downstream

Water discharged from deep reservoirs contains low dissolved oxygen, high carbon dioxide and exceptionally noxious gasses such as hydrogen sulphide and methane causing downstream fish kills. Reduction of downstream flow may also cause negative impacts on fisheries in the floodplain.

Water quality could be improved by increasing dissolved oxygen levels. In the Srinakarin hydroelectric project, discharged water from Srinakarin dam could be held in the Tha Thung Na reservoir which is quite shallow. Water quality could be improved by aeration and by eliminating toxic agents. Moreover, water could be discharged from the metalimnion where water quality is better than in hypolimnion which contains lower oxygen and higher hydrogen sulphide levels.

These management techniques could result in fish production in the new reservoirs which would be maintained at a high level for several years, however, after nutrients from newly flooded soil and the decomposition of flooded vegetation have gone, fish production will decline. Figure 7-1 and Table 7-1 showing that fish landing from Ubolratana reservoir during 1969-1981. Production in 1970 was low at 1384 tons but gradually increased to a maximum of 2556.9 tons in 1974. Production then dropped to 1210 tons in 1980 but increased again in 1981 to 2000 tons. These data may indicate a decline in fish production in Ubolratana reservoir which could occur in other reservoirs in Thailand for reasons mentioned earlier. An increase in the number of fishermen in the reservoir area after impoundment may be another reason for declining fish production. In the Srinakarin and Khao Laem reservoirs, the number of fishermen has also increased significantly following impoundment. They have received substantial economic benefits from these two reservoirs. There were 270 fishing families in the Khao Laem reservoir in 1989. Their average catch was about 5.0 tons/family/year and the average annual household income was 66,323 baht or CND$ 3,316 (Pal Consultants Co.Ltd., and Aggie Consult Co.Ltd. 1990). Fish production in the reservoirs will probably decline in the near future, therefore, an alternative fishery activity should be provided for the fishermen and their families. For example, pen or cage culturing activities could be encouraged as a substitute for open water fisheries. On the other hand cage culture now existing in the Srinakarin and Khao Laem reservoirs does not give a substantial return to the farmers because of the high cost of fish food. Furthermore, intensive cage culture can also increase environmental impacts on the reservoir, and therefore, an experimental study should be done to provide proper techniques for increasing the income of fish-farmers and also for reducing the environmental impacts of these new methods.

Elevated mercury in fish muscle caused by bacterial methylation is the other problem that should be considered seriously. Although its level in fish tissue samples is still lower than the standard for human consumption in North America, the level could increase under certain conditions. In addition, mercury concentrations could be elevated at different rates in different species depending on their feeding behaviour and rate of intake through absorption.

Further studies are required on other fish species and also results should be obtained from other reservoirs where different conditions could lead to different mercury levels in the fish. Other fish species, especially fish existing in the proposed Nam Choan area, should be studied by comparing their mercury levels with the same species in the Srinakarin and Khao Laem reservoirs. The outcome from these investigations could be used to predict mercury levels in fish if the project were to proceed. A mercury monitoring program should be provided to monitor mercury levels in fish caught from these areas and authority should be designated to local officers to prohibit fishing in highly contaminated areas.

In conclusion, fish populations in the reservoir may increase after impoundment, but also increases in mercury concentrations in the fish are likely. Negative environmental impacts resulting from the impoundment could be partially mitigated by providing suitable habitats for fish which affected by the changes, however, elevated mercury from biological sources cannot be reduced. Consequently, a monitoring program is necessary.

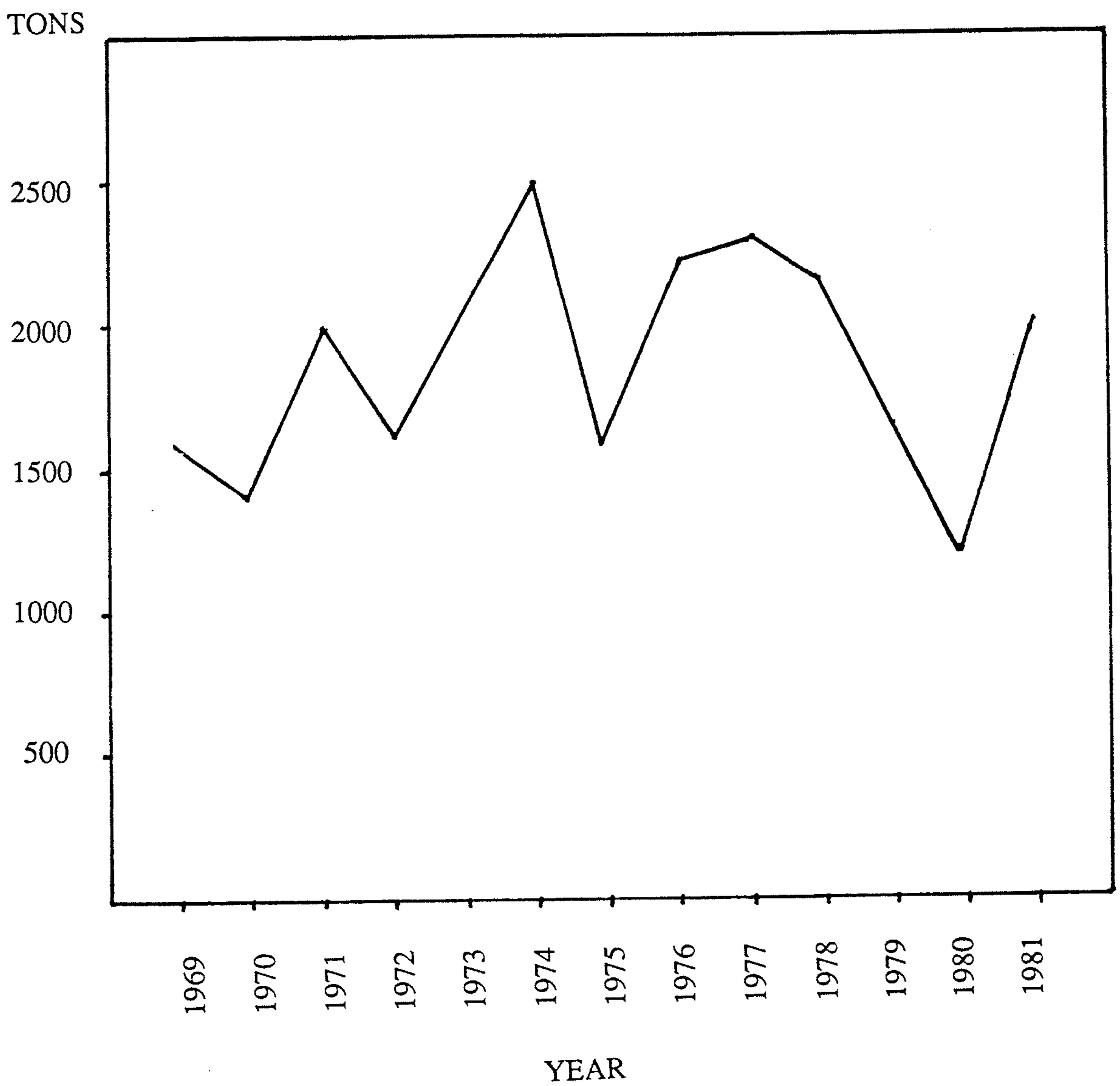


FIGURE 7-1 **AMOUNT OF FISH LANDING AT THE UBOLRATANA RESERVOIR 1969-1981.**

Table 7-1 Economic species collected and annual catch (tons) of each from the Ubolratana Reservoir between 1969 and 1981.

Species/year	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Ophicephalus striatus	46.2	55.5	14.4	34.5	19.7	21.7	13.5	22.6	24.6	19.1	24.4	6.6	13.5
O. micropeltes	53.8	59.0	43.0	0.3	27.9	11.2	9.1	7.9	8.2	6.3	2.4	0.4	1.0
O. lucius	5.9	4.8	20.0	6.3	0.7	0.2	0.2	0.2	t	t	t	t	t
Oxyeleotris marmoratus	53.6	15.7	74.1	126.1	86.8	157.4	46.5	41.6	55.5	73.1	37.9	23.9	29.5
Notopterus notopterus	96.7	142.2	158.4	132.5	64.6	81.2	73.9	76.6	53.8	50.9	41.8	32.7	24.7
Kryptopterus spp. (3 species)	14.3	23.9	68.6	67.1	46.5	23.6	8.8	18.8	23.2	38.9	87.8	102.8	107.3
Wallagonia attu	7.7	6.6	16.3	9.9	8.8	4.4	3.8	4.6	1.6	7.7	16.2	8.6	8.9
Mystus nemurus	7.0	13.7	t	t	t	t	1.9	5.9	11.9	22.2	36.8	16.4	69.8
M. sp.	68.7	102.4	108.0	79.6	48.9	18.6	14.7	24.7	43.0	71.9	62.0	27.6	43.4
Hampala spp.	26.6	31.8	69.7	37.7	41.2	11.8	13.1	10.9	14.5	21.0	10.5	5.1	8.4
Puntius gonionotus	16.0	18.7	35.2	31.6	5.1	20.8	15.4	26.4	45.2	20.9	32.0	7.7	27.7
P. leiacanthus	*	*	502.0	490.8	397.4	500.3	364.5	442.9	399.2	306.6	281.8	205.5	354.8
Osteochielus hasselti	289.9	80.0	237.9	134.0	110.5	176.6	95.0	127.7	113.0	118.8	69.2	49.0	67.0
O. melanopleura	2.0	2.5	t	t	t	t	t	t	44.1	44.0	29.0	11.2	19.5
Morulius chrysophekadion	89.6	88.0	100.5	57.9	114.0	129.1	141.0	131.3	85.0	97.8	25.6	20.5	19.2
Puntioplites proctozysron	-	31.7	36.8	46.1	250.3	506.0	241.2	409.3	430.1	263.9	215.0	120.3	154.1
Cirrhinus jullieni	-	71.4	103.6	323.7	187.2	514.3	278.7	557.3	570.2	597.6	464.5	417.3	722.2
Corica goniognatus	t	t	t	t	t	149.5	309.5	319.2	310.3	298.8	214.9	155.0	311.0
Miscellaneous	776.5	627.6	23.7	7.9	166.2	242.0	105.3	31.7	32.7	51.9	32.9	5.1	14.2
Total (t 1000)	1.55	1.38	1.91	1.60	1.58	2.57	1.73	2.26	2.27	2.11	1.68	1.21	2.0

* Counted as Miscellaneous fishes

t Trace amount

Source : Pawaputanon (1987)

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Appendix 1 Fork length and round weight of fish from Srinakarin, Khao Laem and Nam Choan area.

Species 1 = Pristolepis fasciatus
Species 2 = Puntioplites proctozysron
Species 3 = Hampala macrolepidota
Species 4 = Morulius chrysophekadion
Species 5 = Channa micropeltas
Species 6 = Cirrhinus cryptopogon
Species 7 = Labeo dyocheilus

1. Srinakarin reservoir

Number	Species 1		Species 2		Species 3		Species 4		Species 5	
	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)
1	175	280	155	138	260	450	310	700	440	1150
2	150	185	200	275	260	400	305	750	440	1250
3	120	150	220	320	270	550	290	600	360	700
4	160	205	230	450	290	550	295	650	340	650
5	180	340	180	210	280	650	290	550	320	420
6	180	345	190	208	300	700	290	600	320	450
7	160	195	200	275	330	920	290	650	340	600
8	140	165	210	310	320	820	240	400	230	250
9	170	240	210	305	280	560	290	650	290	360
10	140	145	200	290	340	820	260	600	250	250
11	160	240	190	250	290	650	270	650	280	300
12	150	190	160	155	300	650	300	750	240	220
13	130	120	160	135	290	720	300	700	210	180
14	140	150	200	270	280	550	280	650		
15	140	155	205	295	260	450	280	550		
16	150	195	220	320	240	400	300	750		
17	135	130	200	280	270	500	280	550		
18	160	225	210	310	260	500	300	800		
19	160	245	195	255	290	640	240	400		
20	160	235	200	255	290	700	290	650		
Average	153	206.7	196.7	265.3	285	609	285	630	312.3	521.5

Appendix 1 (cont.)

2. Khao Laem reservoir

Number	Species 1		Species 2		Species 3		Species 4	
	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)
1	230	175	100	105	280	300	220	330
2	290	345	140	175	230	220	145	100
3	280	325	140	175	240	200	100	35
4	220	160	170	215	210	200	130	70
5	260	290	145	195	250	150	120	50
6	270	280	160	175	245	210	120	50
7	290	360	140	130	240	205	130	65
8	250	210	150	225	240	200	140	75
9	200	110	180	250	245	210	220	400
10	210	155	170	215	240	200	200	250
11	290	325	130	110	260	230	145	100
12	320	480	140	115	270	300	195	255
13	340	610	170	205	250	210	135	75
14			140	140	260	230	170	180
15			130	115	250	210	130	60
16			150	150	220	120	145	90
17			150	165	255	220	125	70
18			150	170	225	120		
19			150	165	250	300		
20			170	220	240	150		
Average	265.4	294.2	148.7	170.7	245	209.2	142.8	132.6

Appendix 1 (cont.)

3. Nam Choan site

Number	Species 1		Species 2		Species 6		Species 7	
	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)	Length (mm)	Weight (gm)
1	140	105	230	440	195	250	245	300
2	130	110	235	455	173	170	175	95
3	122	90	235	440	173	145	180	100
4	148	175	215	330	165	120	168	80
5	139	145	187	200	180	190	230	240
6	150	200	180	170	145	90	175	105
7	135	110	187	210	185	205	190	145
8	137	140	226	430	160	110	163	90
9	120	100	165	140	160	130	225	200
10	123	95	243	300	150	110	190	140
11	142	145	175	150	137	80	175	105
12	130	120	213	210	165	125	172	100
13	135	130	142	180	180	200	175	105
14	114	85	165	130	150	110	167	95
15	130	110	185	190	170	170	165	95
16	132	95	130	60	175	180	152	70
17	130	110	130	70	173	150	158	80
18	118	100	125	60	190	220	190	130
19	134	120	115	55	145	90	158	80
20	110	60	133	70	165	125	180	115
Average	130.9	117.2	180.8	214.5	166.8	148.5	181.6	123.5

Appendix 2 Total mercury levels in fish muscle

Species 1 = *Pristolepis fasciatus*
Species 2 = *Puntioplites proctozysron*
Species 3 = *Hampala macrolepidota*
Species 4 = *Morulius chrysophekadion*
Species 5 = *Channa micropeltas*
Species 6 = *Cirrhinus cryptopogon*
Species 7 = *Labeo dyocheilus*

Site 1 Srinakarin reservoir

Number	Species 1		Species 2		Species 3		Species 4		Species 5	
	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)
1	0.14	175	0.03	155	0.25	260	0.04	310	0.09	440
2	0.09	150	0.05	200	0.02	260	0.04	305	0.20	440
3	0.06	120	0.08	220	0.07	270	<0.01	290	0.09	360
4	0.09	160	0.04	230	0.21	290	<0.01	295	0.12	340
5	0.08	180	0.05	180	0.08	280	0.04	290	0.10	320
6	0.10	180	0.03	190	0.14	300	0.02	290	0.11	320
7	0.08	160	0.09	200	0.33	330	0.03	290	0.13	340
8	0.15	140	0.10	210	0.36	320	0.04	240	0.06	230
9	0.12	170	0.08	210	0.10	280	0.05	290	0.07	290
10	0.11	140	0.06	200	0.31	340	0.05	260	0.09	250
11	0.18	160	0.06	190	0.13	290	0.04	270	0.07	280
12	0.19	150	0.05	160	0.23	300	0.05	300	0.08	240
13	0.11	130	0.05	160	0.18	290	0.02	300	0.04	210
14	0.09	140	0.07	200	0.26	280	0.05	280		
15	0.14	140	0.05	205	0.09	260	<0.01	280		
16	0.21	150	0.06	220	0.28	240	0.04	300		
17	0.07	135	0.06	200	0.09	270	0.03	280		
18	0.10	160	0.05	210	0.07	260	0.05	300		
19	0.14	160	0.06	195	0.19	290	0.01	240		
20	0.12	160	0.03	200	0.07	290	0.06	290		
Arithmetic means	0.12	153	0.06	196.7	0.17	285	0.03	285	0.10	312.3

Appendix 2 (cont.)

Site 2 Khao Laem Reservoir

Number	Species 1		Species 2		Species 3		Species 4	
	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)
1	0.05	230	0.06	100	0.24	280	0.04	220
2	0.11	290	0.05	140	0.21	230	0.01	145
3	0.05	280	0.03	140	0.33	240	0.01	100
4	0.07	220	0.07	170	0.22	210	0.01	130
5	0.09	260	0.06	145	0.24	250	0.02	120
6	0.08	270	0.04	160	0.15	245	0.02	120
7	0.09	290	0.06	140	0.48	240	0.01	130
8	0.59	250	0.06	150	0.42	240	0.01	140
9	0.09	220	0.12	180	0.51	245	0.04	220
10	0.07	210	0.09	170	0.25	240	0.02	200
11	0.12	290	0.08	130	0.31	260	0.02	145
12	0.10	320	0.03	140	0.48	270	0.02	195
13	0.07	340	0.09	170	0.40	250	0.02	135
14			0.07	140	0.25	260	0.02	170
15			0.11	130	0.45	250	0.02	130
16			0.06	150	0.29	220	0.02	145
17			0.07	150	0.28	255	0.01	125
18			0.06	150	0.63	225		
19			0.05	150	0.45	250		
20			0.06	170	0.34	240		
Arithmetic means	0.12	265.4	0.07	148.8	0.35	245	0.02	142.8

Appendix 2 (cont.)

Site 3 The proposed Nam Choan site

Number	Species 1		Species 2		Species 6		Species 7	
	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)	[Hg] (ug/g)	length (mm)
1	0.15	140	0.03	230	0.02	195	0.01	245
2	0.03	130	0.01	235	0.01	173	0.01	175
3	0.14	122	0.08	235	0.02	173	<0.01	180
4	0.09	148	0.01	215	0.05	165	<0.01	168
5	0.10	139	0.02	187	0.01	180	0.01	230
6	0.03	150	0.02	180	0.03	145	<0.01	175
7	0.09	135	0.02	187	0.03	185	<0.01	190
8	0.09	137	0.02	226	<0.01	160	<0.01	163
9	0.12	120	<0.01	165	0.01	160	0.04	225
10	0.12	123	0.03	243	0.02	150	0.01	190
11	0.08	142	0.01	175	0.03	137	0.01	175
12	0.14	130	0.04	213	0.02	165	<0.01	172
13	0.03	135	<0.01	142	0.01	180	0.01	175
14	0.06	114	<0.01	165	0.01	150	0.02	167
15	0.09	130	0.02	185	<0.01	170	<0.01	165
16	0.03	132	0.01	130	0.03	175	<0.01	152
17	0.06	130	0.02	130	0.07	173	0.01	158
18	0.10	118	0.01	125	<0.01	190	0.01	190
19	0.06	134	<0.01	115	<0.01	145	0.01	158
20	0.05	110	0.03	133	0.01	165	0.01	180
Arithmetic means	0.08	130.9	0.02	180.8	0.02	166.8	0.01	181.6

Appendix 3 Mean mercury concentrations standardized by regression analysis for mean fork length of fish in each sample.

Species	Fork length (mm) used for calculation	Site			Mean
		1	2	3	
Pristolepis fasciatus	175	0.12	0.09	0.06	0.09
Puntioplites proctozysron	175	0.05	0.07	0.01	0.04
Hampala macrolepidota	260	0.10	0.33	-	0.21
Morulius chrysophekadion	210	0.02	0.03	-	0.02

Appendix 4 One Way Analysis of Covariance Table

Species	Source	Df	SS	MS	F-Ratio	F-Prob
Pristolepis	Total Treatment Error	51 2 49	2.6459 .3159 2.3300	.1580 .0476	3.3221	.04436
Puntioplites	Total Treatment Error	58 2 56	7.5438 5.1187 2.4251	2.5593 .0433	59.0992	0.00000
Hampala	Total Treatment Error	38 1 37	3.5356 1.4476 2.0880	1.4476 .0564	25.6513	0.00001
Morulius	Total Treatment Error	35 1 34	2.8638 .0649 2.7989	.0649 .0823	.7887	.38072

Table of Y Means

Species	Treatment name	Unadjusted Y Mean	Adjusted Y Mean	Stand. Dev	N
Pristolepis	Site 1 Site 2 Site 3	-.9498 -1.0315 -1.1356	-.9456 -1.0578 -1.1227	.0488 .0605 .0488	20 13 20
Puntioplites	Site 1 Site 2 Site 3	-1.2638 -1.2066 -1.8231	-1.3424 -1.1138 -1.8372	.0465 .0465 .0465	20 20 20
Hampala	Site 1 Site 2	-.8524 -.4875	-.9377 -.4022	.0531 .0531	20 20
Morulius	Site 1 Site 2	-1.5731 -1.7698	-1.7521 -1.5592	.0642 .0696	20 17

Appendix 5 Sample mean for mercury concentrations

Species 1 = *Pristolepis fasciatus*

Species 2 = *Puntioplites proctozysron*

Species 3 = *Hampala macrolepidota*

Species 4 = *Morulius chrysophekadion*

Site 1 = Srinakarin reservoir

Site 2 = Khao Laem reservoir

Site 3 = Nam Choan Project

	Species 1			Species 2			Species 3		Species 4	
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 1	Site 2
Sample Size	20	13	20	20	20	20	20	20	20	17
Arithmetic Mean	0.12	0.12	0.08	0.06	0.07	0.02	0.17	0.35	0.03	0.02
Adjusted Mean	0.11	0.09	0.07	0.04	0.08	0.01	0.11	0.40	0.02	0.03
ANACOVA Mean	0.12	0.09	0.06	0.05	0.07	0.01	0.10	0.33	0.02	0.03